Science Report

The Milky Way and Resolved Stellar Populations Working Group

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1 Executive Summary

Thanks to its large collecting area, wide field of view, high multiplexing and dedicated scheduling for surveys, MSE will provide a fully unique tool to study in unprecedented detail the stellar populations of the Milky Way and the Local Group.

2 Science overview

A brief overview of the key science cases for MSE in this area. In particular, be sure to discuss any important science in which MSE is expected to contribute but which has not been developed into SROs (note that each specific SRO will be discussed in detail in the Appendices, so discussion of these should be kept to an overview-level only)

Here are the different SROs developed by the WG and provided in Appendices.

- Galactic Interstellar Medium [A.1]
- Stellar Astrophysics [A.2]
- Metal-Poor Stars [A.3]
- Milky Way Archeology [A.4]
- Stream kinematics as probes of LCDM lumps [A.5]
- Dynamics and chemistry of the Local Group dwarf galaxies [A.6]
- A chemodynamical deconstruction of M31 & M33 [A.7]

An extra SRO was added to discuss the provision to later upgrade the resolution:

- Exploring R>90000 option for MSE [A.8]

An other SRO will be prepared on Exoplanet science later on: planet-induced chemical signatures. One needs many sky fibres to carefully monitor and calibrate the sky transmission to tease out the tiny planetary atmosphere signature; MSE would be perfect for this since the competition (e.g. GMT/GMACS) will be even more oversubscribed. A high resolution and high SNR is needed for this science case observing very bright stars.

3 Science synergies with other facilities

Highlight any and all opportunities for science synergies or direct collaboration with other facilities that will exist, or are expected to exist, on a similar timescale to MSE.

- Gaia: The final Gaia data release will be available at the MSE start. MSE will be able to exploit all the Gaia parameters to fully optimize its target selection for sources with $G < 20$. It will be able to follow at high resolution all the Gaia discoveries that will continue to be made long after the final release (new clusters, new streams, new dynamical structures in the Milky Way disc, new Milky Way history signatures predicted by updated models, rare objects, ...).
- Pan-STARRS, Subaru/HSC, LSST: Those deep photometric surveys will provide faint star input astrometry and photometry for MSE target selection and analysis. MSE will provide follow-up for LSST transients.
- Euclid: targets up to magnitude 24 at high latitude
- Kepler, TESS, PLATO: MSE high resolution high multiplex will enable a detailed follow-up of current and new asteroseismology and exoplanet missions (See A.2).

4 Competition

Highlight all facilities in which MSE will face competition in this science area. Discuss, as quantitatively as possible, how much better MSE will be compared to this competition (and how much better MSE should position itself to be).

Largely based on Table 2 of the Feasibility Study, here are the different "competitors" combined in three categories: R>30,000, R∼20,000 and 5,000<R<15,000. However those instruments listed here are more complementary than competitors.

Table 1: Resolution $\geq 30,000$

Instrument	D	Ω	R	λ	Hem.	N_{mos}	Stellar surveys
FLAMES/UVES	8	0.14	47,000	Optical	South	8	Gaia-ESO
MMT/Hectoechelle	6.5	0.79	38,000	Optical	North	240	no survey
AAT/HERMES	3.9	3.14	28,000-50,000	Optical	South	392	GALAH

If the point design of MSE is changed to allow to go at higher resolution, it would be a unique instrument. Even after the Gaia-ESO survey, the UVES number of stars cannot compete. HERMES magnitude limit is much smaller (note also that R=28,000 is the HERMES baseline). Both instruments are in the South. MMT/Hectoechelle is not available to most of the MSE community and does not plan any large scale stellar survey. The science case for such a high resolution is clearly demonstrated in Section 5.

This resolution corresponds to the current MSE baseline. Several instruments are planned within this resolution range, in particular for the Gaia follow-up. MOONS being in the South and observing in the NIR with a smaller FoV, it could actually be seen more as a complement to MSE than a competitor. MSE superside GIRAFFE by the number of targets and the FoV. It superside WEAVE and 4MOST by the magnitude limit, which is $V < 17$ for those 4m telescopes (See Table 1 of A.4 for the outstanding differences between a 4m and a 10m for Galactic Archeology). Magellan/IMACS does not plan large scale stellar survey. MSE will therefore be the only telescope allowing to reach millions of the faintest Gaia stars ($G = 20$) in high-resolution in the optical (but see the GCT/IRS project, although with a very small FoV).

Table 2: Resolution $\sim 20,000$

Instrument	D	Ω	R	λ	Hem.	N_{mos}	Survey / Status
VLT/GIRAFFE HR	8	0.14	20,000	Optical	South	130	Gaia-ESO
APOGEE-2	2.5	1.5	22,500	NIR	N & S	300	SDSS-III
Magellan/IMACS	6.5	0.16	16000	Optical	South	400	no survey
WHT/WEAVE	4.3	3.14	20,000	Optical	North	1000	Final Design
VLT/MOONS	8.2	0.14	20,000	NIR	South	1000	Phase A
VISTA/4MOST	4.1	3.0	20,000	Optical	South	1500	Preliminary Design
GCT/IRS	10	0.05	20,000	Optical	North	1000	project

Table 3: Resolution $5,000 < R < 15,000$

Instrument	D	Ω	R	λ	Hem.	N_{mos}	Survey / Status
VLT/GIRAFFE LR	8	0.136	5,600	Optical	South	130	-
LAMOST	4	19.6	10,000	Optical	North	4000	survey
Keck/DEIMOS	10	0.023	5500	Optical	North	150	-
WHT/WEAVE	4.3	3.14	5,000	Optical	North	1000	Final Design
GCT/IRS	10	0.05	10,000	Optical	South	1000	project

Radial velocities for the Gaia faint stars can be obtained from the planned medium to low resolution instruments on 4m. MSE would concentrate with this resolution mode on faint stars ($G > 20$) for Local Group science [A.6,A.7] and deep survey follow-up (SDSS, Pan-STARRS, LSST), in particular for halo streams [A.5] and white dwarfs survey as a tool to date galactic populations [A.2].

5 Key capabilities for MSE to deliver transformative science

Related to the above, draw special attention to any capabilities that emerged during the SWG activities as being particularly important, unique, science-enabling, or desirable. Bear in mind that it is the science cases presented herein, in particular the SROs, that will set the initial science requirements of MSE. A baseline (point) design is presented in the Feasibility Study, but the SWGs should not be limited in science scope or ambition because of this baseline. Instead, the SWGs should initially consider MSE to be a large aperture, wide field, highly multiplexed, optical/NIR spectroscopic facility working at a range of spectral resolutions. Very dramatic departure from the baseline will require compelling science goals, but such departure is potentially possible. When considering the necessary science capabilities, and in anticipation of likely technical challenges, please pay special attention to the following issues/questions, and explicitly address them in your report (with reference to specific science goals):

1. Blue sensitivity: *1. If your science requires access to the blue (<400nm), exactly how blue is (i) required? (ii) desired?* Required for neutron-capture elements at least to 370 nm, and even desired to 350 nm if possible [A.2]. Desired for stellar evolution Be and OH lines [A.2]. Desired for ISM [A.1] (see Table 4 of the Feasibility Study providing the important ISM diagnostic features). Desired for white dwarfs [A.2]: blue coverage down to 370 nm enable to cover the higher Balmer lines that are most sensitive to surface gravity, and hence mass.

2. NIR sensitivity: *Is access to the NIR required or desired? J band? H band? Even redder?* NIR is desired to go though the dust towards the inner disk and bulge. In the NIR the line blending in the spectra of cool metal-rich stars is reduced. It will however bring less

heavy n-process elements and be less suited for FG metal-poor stars. It will also be more directly in competition with MOONS.

3. Wavelength windows: *It is possible that the complete wavelength range (full optical through NIR) will not be accessible in one shot, particularly at intermediate and high resolutions. If so, what should the wavelength windows be in these settings? (or at least, what wavelengths are critical to access?)* Nothing new here compared to the feasiblity study for the WG. Guidelines from the GYES project (if two bands) or the GHOST/HERMES surveys (if 3-4 bands) could be followed.

4. Intermediate spectral resolution: *Are there strong science drivers for an intermediate resolution mode ($\sim 5-10K$)?* Local Group and halo streams: SROs A.6, A.7, A.5 + faint white dwarfs in A.2.

5. Are there strong science drivers for a spectral resolution significantly higher than described in the point design? Yes ! See details in SROs A.1, A.2, A.3, A.4, A.6, A.8. Large scale surveys at R$\sim 20,000$ are on-going (Gaia-ESO, GALAH) and planned (WEAVE, 4MOST, MOONS). MSE will go deeper than the 4m projects and therefore reach the outer disk, the outer halo, the bulge turn-off, faint Local Group stars. However those surveys will reach the limits of what can be acheived with 0.1-0.2 dex accuracy in terms of stellar population labelling. By moving to a significantly higher resolution, MSE will do something really new: it will provide accurate characterisation and detailed abundances of numerious chemical elements for millions of stars, uniquely enabling the most detailed stellar and interstellar diagnostics up to the Local Group. The need for an even higher resolution R$> 90,000$ being limited to quite specific studies [A.8], a large scale R$\sim 40,000$ survey of millions of stars would be the ultimate spectroscopic survey for galactic and Local Group archeology, stellar astrophysics, ISM science.

6. *Is there a need for your science to be able to switch between resolution settings quickly (e.g. on the same night or between subsequent nights)?* LSST follow-up of supernovae may need this (TBD). *Is there any science reason why you would want to observe multiple targets in the same field at different resolutions simultaneously?* Such a possiblity would be useful to combine high resolution for the brightest stars with low resolution for the faintest stars on the same field. That could optimize the survey strategy, in particular for the Local Group dwarfs [A.6]. However considering the faint magnitude limit of MSE and its wide field of view, an optimized survey strategy combining Galactic, Local Group and Extragalactic (IGM in particular) science could allow to fill the fibres efficiently even for the high resolution at high galactic latitude. The exception being the R>90,000 option.

7. Spectrophotometry: Does your science require very accurate spectro-photometry? No.

8. IFUs: *Are there strong science drivers for either (a) some fibres forming a fixed IFU bundle within the MSE focal plane (b) a multi-object IFU capability. Note that the latter has been suggested as an upgrade path (i.e., not first light), since it potentially requires only a different focal plane+fibre set-up, not a different suite of spectrographs. Is there obvious science support for this? Is there a strong science driver for it to be a first light capability (in addition to the MOS, not instead of the MOS). Would ability to cluster individual fibres to create a single or multiple sparse-packed IFU be (a) interesting (b) sufficient for these science cases?* None.

9. Upgrade paths: *Are there ideas for how MSE might be upgraded after first light? i.e., are there capabilities that you would like to see eventually and which would be science-enabling,*

but which are not necessary or realistic for first light (Note: this question recognizes that we do not want to design out any capabilities that might prove interesting) R>90,000 [A.8]

6 Avenues for future work

Discuss work that the SWG deems important for the future development of these science areas that has not yet been addressed by the current work. Indicate how critical, and on what timescale, this work needs to be addressed. In particular, be sure to highlight any science cases that currently require unproven or undemonstrated techniques. All the science cases described here can be done with proven techniques. A key science case that has to be developed in the coming months is the one on Exoplanet science.

A Appendices

A.1 SRO Galactic Interstellar Medium

A.2 SRO Stellar Astrophysics

A.3 SRO Metal-Poor Stars

A.4 SRO Milky Way Archeology

A.5 SRO Stream kinematics as probes of LCDM lumps

A.6 SRO Dynamics and chemistry of the Local Group dwarf galaxies

A.7 SRO A chemodynamical deconstruction of M31 & M33

A.8 SRO Exploring the R>90000 option for MSE

Science Reference Observation

Galactic Interstellar Medium

Rosine Lallement

January 21, 2015

1 Abstract

This SRO covers Galactic Interstellar Medium (GISM) using high-resolution spectroscopy. This SRO combines inputs from the Feasibility Study and White Papers.
A specificity of this topic is that ANY spectral observation of Galactic and extragalactic targets contains information on the GISM through the absorption features that are imprinted by intervening matter and through the reddening (or differential absorption). On the other hand, specific observations and surveys can be conducted with MSE to make unprecedented progresses in GISM mapping and understanding.

2 Science justification

We summarize here the main scientific advances to be obtained on the GISM with MSE.

- **Adding the third dimension to the Galactic ISM**

Paradoxically the Milky Way ISM is extremely well mapped in 2D at many wavelengths but extremely poorly mapped in 3D due to the absence of information on the distance to the IS matter (ISM) generating the emission. MSE can bring the distance-limited observations required to produce realistic 3D density and velocity distributions of the GISM, gas and dust. Such a construction wiill make full profit of the foreseen Gaia parallax measurements. Those maps will be an invaluable general tool in many fields (radiation and particle propagation, foreground, background, environment identification…).

- **Understanding the multi-phase structure of the Galactic ISM**

Accessing absorption by different tracers will give the tools to model the physical , dynamical and chemical properties of the molecular, diffuse and ionized GISM phases and their space distributions in relation with stellar winds and SNR hot cavities, allowing to understand the interplay between the phases, and the role of radiation , energetic particles, magnetic field, etc.

- **Understanding the ISM history in relation with the stellar history**

The detailed structure of the ISM will be compared for the first time with a detailed Galactic archeology information also provided by MSE, allowing to better understand the stellar formation-ISM feedback mechanisms and the combinded star-ISM evolutionary processes in all regions of the Milky Way, including bulge, halo and thin-thick disk.

- **Adding invaluable constraints on the potential carriers of the Diffuse Interstellar Bands (DIBs)**

Through measurements and distance and ISM-phase assignment of the hundreds of diffuse bands detectable in the optical, MSE will bring new constraints on the species that are responsible for the DIBs and their conditions of formation.

MSE will be the only instrument able to observe at high resolution millions of objects with known distance, allowing an outstanding step forward in the knowledge of the galactic ISM.

2 Key astrophysical observations

Key measurements f<u>or general mapping</u>: In order to build 3D maps with high spatial resolution and at large distance the main measurements are those of the gaseous lines and bands that are easily extracted and allow the best estimate of evolution with distance of the ISM matter. Note that a strict proportionality between the column density of H and the tracer is not required for mapping, what is used is the spatial gradient.

-Nearby targets:
Information can be extracted from the "classical" and strong lines: NaI (589.0_589.6nm), CaII (393.4-396.8nm), CaI (422.7nm) for the gas and from the reddening for the dust. The strongest diffuse bands 578.0, 579.7, 628.4, 619.6, 661.4 nm are also the most appropriate.
-Distant targets:
While the strong lines can still be used above the Plane or in directions here clouds are distributed in velocities, weaker lines more appropriate for large optical depths (to avoid saturation) are NaI (330nm doublet) and KI (769.9nm), and the weaker diffuse bands (numerous and distributed above 430 nm).

Key measurements for ISM phase studies and wavelength coverage.
While the ionized and diffuse atomic ISM fraction is best traced in the optical, the molecular and dense atomic phase phase is best traced when access to the blue is provided. Molecular clouds are detected with CH(430nm), CH+ (423nm) , CN (387nm) and also metallic lines such as TiII (323,324, 338nm), TiI (363nm), FeI (386nm), MnI, NiI, AlI (394nm). Alternatively the molecular phase can be probed with the infrared bands of C2 around 878 nm).

Requirements
High spectral resolution is mandatory to disentangle ISM lines or bands from stellar features and also to allow kinematical analyses. High resolution strongly decreases the lower limit on the quantity of absorbing matter that can be detected since most lines are narrow.
A resolution R>40,000 has already been proven to allow this disentangling and a cloud-by-cloud analysis. A lower resolution (e.g. R=20,000) allows some DIBs and lines to be extracted but severely limits the kinematical analysis and will ultimately strongly decrease the achievable spatial resolution on the mapping.

Sky emission/absorption
Sky emission must be removed properly as it affects the main lines (e.g. NaI emission). Fibers must be devoted to this in sufficient number to allow a proper treatment. Sky absorption correction can be done through atmospheric transmission modeling that has considerably progressed in the last years.

4 Target selection

As already noted, any target provides some information, thus the GISM mapping benefits from all other programs. However, a full 3D mapping program requires a large survey combining sky-covergae and a good distribution of targets with distance. Note that such a survey is feasible ONLY with a facility like MSE combining high resolution, sensitivity, high multiplex and and wide field and could be one of the major first programs.

5 Cadence, calibration, data processing

Single observations are enough. Standard calibration and data processing are similar to those of stellar observations.

Science Reference Observation Template for Stellar Astrophysics

Please send comments to K.A. Venn (kvenn@uvic.ca)

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1. Abstract

2. Science Justification

Current and planned surveys at 2-4 m telescopes will target every stellar population in the Galaxy, providing spectra for 10^5 to >10^6 stars, at high and medium resolutions, and have the ability to monitor spectral variation. In addition, the Gaia-ESO survey at the VLT 8-m facility can observe small fields of view as deeply as MSE, e.g., globular clusters and the Magellanic Clouds. Many scientific studies of the dominant stellar populations will have been carried out, nevertheless the increased statistical sampling of the MSE could open new avenues of investigation in those populations. There will also be stellar populations that are not easily accessible in the previous surveys, thus the MSE wide-field multi-object programs could have a transformational impact on studies of stars in the outer halo field, the outer disk, and/or the faintest objects in the Bulge. MSE will also have the unique ability to spectroscopically monitor time variable objects, and to support large imaging and possibly astroseismic surveys. We summarize these science cases in this SRO.

The dominant stellar populations that will be observed in significant numbers by the ongoing or planned surveys include those in the Galactic disks, bulge, inner halo, star clusters, and nearby dwarf galaxies. While the MSE will cover nearly a quarter of the Galactic volume and survey ~5 million stars, increasing the sample sizes of these dominant stellar populations could open opportunities for and original science questions related to stellar structure, stellar processes, and/or local environment. Furthermore the discovery of new examples of rare objects through blind surveys, e.g., Li-rich stars, C-rich stars, solar twins and solar analogues, peculiar AGB stars, metal-line white dwarfs, or even potentially first star remnants (e.g., Rameriz et al. 2010, Liu et al. 2014, Carollo et al. 2014, Datson et al. 2014, Venn et al. 2014, Koester et al. 2014, Aoki et al. 2014) can have a transformative impact in modeling their phenomena. This extends to increasing the sample sizes of objects in the nearby dwarf galaxies, where differences in their environments and histories can provide important constraints for stellar nucleosynthesis, e.g. progenitor mass and metallicity dependent yields from AGB and SN events (e.g., Shetrone et al. 2003, Venn et al. 2004, Herwig 2005, Heger & Woosley 2010, Nomoto et al. 2013, Frebel et al. 2014, Schneider et al. 2014).

The stellar populations that will be difficult to access in the previous spectroscopic surveys include those in the outer halo, outer disk, and faint stars in the bulge. The MSE high resolution (HR, R = 20,000), or even very high resolution (VHR, R > 40,000) spectroscopic modes can provide high precision in stellar parameters, radial velocities, rotational velocities, chemical abundances, and isotopic ratios (also see the SRO for R > 90,000 science cases), which are often needed for detailed stellar modeling and observational testing. *In the outer halo*, HR and VHR spectra of unique stars (e.g., chemically peculiar stars, remnants of first stars, RR Lyrae stars, and halo dwarfs) could provide new information for stellar nucleosynthetic yields, stellar pulsation theory, and ages for halo white dwarfs (e.g., Ivans et al. 2003, Aoki et al. 2013, 2014, Yong et al. 2013, Cohen et al. 2013, Drake et al. 2013, Kilic et al. 2005, Kalirai 2012). *In the outer disk*, young metal-poor stars found in star forming regions can be compared to the typical outer disk field stars, providing valuable information on the outer disk star formation environment (e.g., Friel et al. 2010, Frinchaboy et al. 2013, Carrero et al. 2015). *In the Galactic bulge*, stars tend to be more metal-rich than in the solar neighbourhood and likely to have formed early, thus HR and VHR spectroscopy of the faint stars (dwarfs, and those in high extinction regions) could provide unique constraints for stellar nucleosynthesis, stellar interiors, and stellar atmospheres at higher metallicities, in higher density environments, and with unique chemical compositions (e.g., Fulbright et al. 2006, 2007, Bensby et al. 2010, 2011, Garcia Perez et al. 2013, Johnson et al. 2014). These populations are present in the MSE SRO on Galactic Archaeology, but we include them here as well to highlight that HR and VHR observations would also impact Stellar Astrophysics.

Repeat observations in a spectroscopic survey can also be used to detect time variability phenomena. The ongoing and planned spectroscopic surveys already have this ability, though only the SDSS-APOGEE survey appears to use multiple observations to reach their SNR requirements, and have spaced those to also enable the search for variability (e.g., Deshpande et al. 2013). Nevertheless, the timing for MSE could make it unique if it is used to support the planned large photometric, asteroseismic, and other survey projects. In an era of large imaging surveys (e.g., Pan-STARRS, DEC, Skymapper, and Euclid), transit/asteroseimology/variability programs (e.g., LSST, TESS, and PLATO), and the Gaia proper motion survey, then all-sky spectroscopy provides radial velocities for full 6D phase space, accurate temperatures and metallicities for exoplanet hosts, and simple follow-up on new objects. With some thought to the cadence of the MSE observations, then it could play an important *supportive* role in time domain stellar spectroscopy. Spectral monitoring of transients, transit-selected planetary host candidates, binary stars, pulsating and/or eclipsing variables, and also supernovae, could all lead to transformational science in Stellar Astrophysics.

3. Key Astrophysical Observables

The key measurements for studying stellar astrophysics are well-defined spectral line features for accurate stellar parameter (temperature, gravity, metallicity, rotational velocities, magnetic fields strengths, etc.) chemical abundances, and radial velocities or transient events. Therefore, most stellar astrophysics science requires high- resolution spectroscopy for precise determinations (except in the case of white dwarfs where pressure broadening makes R> 2000 unnecessary). SNR and wavelength range can also play important roles. These are described further here:

Resolution and SNR: High-resolution work is necessary to deblend critical atomic lines, determine precision rotational and radial velocities, and calculate accurate chemical abundances. At R=20,000 (R=40,000), synthetic spectra show that lines are deblended at ~0.2 A (0.1 A), rotational and radial velocities to better than ~0.2 km/s (0.1 km/s) through cross-correlation of many lines (>100), and chemical abundances with Delta log(X/Fe) <0.15 dex (0.1 dex), when SNR>30. This precision is necessary for most science cases that involve detailed stellar studies (e.g., Tolstoy et al. 2009, Carretta et al. 2009, Hunter et al. 2009, Brandt & Huang 2015). As an independent example, the CFHT/GYES document also showed that R=20,000 yields [Fe/H], [alpha/Fe], and 5-10 additional elements, whereas R>40,000 provides higher precision and more chemical elements (Bonifacio et al. 2010). A higher-resolution mode is used for analyses of neutron capture elements (where deblending the few available lines is more critical), and in more metal-rich stars and cool stars where blending is an increasing problem. This could be important in studying exoplanet hosts, which tend to be cooler, metal-rich stars (Buchhave et al. 2012, 2014, Rameriz et al. 2014, Wang & Fischer 2015). This high precision is also useful when studying the radial velocities of binary stars, and subsequently determining orbits and masses.

Wavelength range: Most stellar spectroscopy has been carried out from 390 – 900 nm due to atmospheric throughput and the sensitivity of the available detectors (from photographic film to CCDs). Therefore, most stellar astrophysics, including stellar atmospheric models and precision atomic data, has been developed for this wavelength range. Pushing to bluer wavelengths has opened new science cases e.g., neutron-capture elements (Os, Dy, Er, U, Th) for cosmochronology, and Be and OH lines for studies of stellar evolution, all of which occur between 310-390 nm (Hill et al. 2002, Francois et al. 2007, Boesgaard et al. 2011, Roederer et al. 2012, Pasquini et al. 2014). Pushing to near-IR wavelengths has recently been improved by the APOGEE survey (1.5-1.7 microns), where atomic data and stellar models can now provide precision abundances for OH, CH, CO, CN bands, as well as new spectral lines of common elements (Meszaros et al. 2012, Smith et al. 2013, Lamb et al. 2015). Additional spectral lines always improve precision by reducing random errors and permitting new investigations of systematic errors. A preference would be to push towards bluer wavelengths (≤ 370 nm) for more neutron-capture elements.

Wavelength stability: Only time domain spectroscopy requires exquisite wavelength stability. The current gold standard is the ESO HARPS spectrograph, which has provided ~1 m/s radial velocity precision for nearly a decade. It uses two 1” fibers (object + sky or ThAr), feeding an optical spectrograph (378-691 nm) contained in a vacuum vessel to avoid spectral drift due to temperature or air pressure variations. While the HARPS resolution (R=115,000) is much higher than that considered for MSE, mechanical stability at any resolution is a benefit in stellar multiplicity, variability, and exoplanetary system research.

4. Target selection

Target selection for an all-sky survey naturally benefits from broad-band imaging surveys. In the next decade, several (some public) imaging surveys are planned: Pan-STARRS, DEC, Skymapper, LSST and Euclid. All of these have multi-wavelength photometry, permitting initial estimates at stellar parameters, and some have multiple-epoch observing for selecting transients, binary stars, pulsating stars, etc., and with a priori light curves. The limiting magnitudes (e.g., V ~ 24 in Pan-STARRS) in all are below those necessary for target selection for spectroscopy (V ~ 19, for SNR > 30), and the photometric precision does not need to be extremely accurate for target selection (e.g., ΔV~0.01 as in Pan-STARRS is excellent). Even the Gaia limiting magnitude (g~20) is within reach of the MSE high-resolution survey, if lower SNR is acceptable. The 2MASS and WISE satellite databases are also useful resources for longer-wavelength photometry of brighter stellar sources (e.g., 2MASS includes over 250 million point sources with high SNR and H≤15). U-band photometry will be available after LUAU (CFHT large program, granted in 2014, PIs McConnachie & Ibata) before MSE becomes available, helping to identify hot and metal-poor stars. Narrow band photometry (e.g., CFHT CaH&K filter photometry through the PRISTINE program, granted time in 2015, PI Starkenburg) can also help fine-tuned target selection for metal-poor stars.

5. Cadence and temporal characteristics

The MSE all-sky survey will likely require multiple 1-hour exposures of individual targets to reach the SNR requirements, therefore if we consider the observing cadence of these observations then it may be possible to use these spectra to search for and characterize variability. The specific cadence is not currently clear though, e.g., RR Lyrae variables have periods < 1 day, Cepheid periods range from weeks to years, giant planet orbits are typically weeks to years as well, and CEMP-s stars have orbital periods that are ~ a year (Lucatello et al. 2005), thus, the specific time frame cannot be determined without knowing the science case. On the other hand, if fields are to be re-observed over 1-2 years, then planning multiple observations with *log*(time) displacements is one way to avoid aliasing period determinations. As one example, the SDSS-MARVELS program uses a baseline cadence of 33 visits over 18 months; 15 visits are concentrated within a two-month period to resolve short period variations, 5 more observations are spread over the first year, and two observation per month in the second year to resolve longer periods, phases, and amplitudes (Ge et al. 2008, Lee et al. 2011). Serendipitous discoveries of variable stars (binaries and stellar multiplicity, pulsating stars, eclipsing, and eruptive stars) are expected, possibly even in the 100's per night from the LSST survey alone (after its first year where much higher rates are expected, Ridgway et al. 2014). Other time-critical observations, such as transients, are best served as PI science programs.

6. Calibration Requirements

With observations of ~5 million stars, then standardized data taking and data reduction will be necessary of the spectra, including wavelength calibrations, flat fielding, and sky subtraction. Flux calibrations for detailed spectral energy distributions are not essential, however spectra of several rapidly rotating hot stars taken at a variety of air masses each night will be necessary to remove telluric features. In terms of the data reduction and calibration requirements, there are no significant differences between the MSE stellar spectra and other current and planned spectroscopic surveys at the 2-4 m telescopes or the Gaia-ESO survey. Those surveys are currently developing exquisite data reduction tools and pipelines (e.g., Sacco et al. 2014), and therefore the MSE should adopt these and/or similar tools for its high-resolution stellar spectra reductions.

7. Data processing

Starting from 1-dimensional, reduced and sky-subtracted spectra (discussed above), then it is necessary to identify and measure spectral lines. This stage can be improved by line fitting software (e.g., DAOSpec, Stetson & Pancino 2008) and curated line lists (e.g., VALD, Heiter et al. 2008). Data analysis that involves stellar parameters and chemical abundances then requires some sort of model atmospheres analysis. The ongoing and planned spectroscopic surveys currently use grids of stellar spectra for a χ^2-fitting or more sophisticated fitting algorithms (e.g., Lee et al. 2011, Allende Prieto et al. 2015; also, principle components analysis by Ting et al. 2012, optimized pattern recognition by Kordopatis et al. 2011, etc.). This is sufficient for the vast majority of stellar observations, however the results are limited by the grid edges and available calibrations. Further data analysis tools would be helpful for Stellar Astrophysics, e.g., simultaneous errors analysis, co-addition of repeated spectral observations or tools for basic variability analyses. Cross-listing the stellar spectral results with other surveys, such as the large imaging and photometry surveys or the GAIA proper motions, could provide quick kinematic information for targets, or lead to preliminary light curves for variables. The analysis of stellar spectra can be easily misled within a simplified pipeline and grid analysis, e.g., for chemically peculiar stars not represented in the grid or emission line objects, thus raw data, science grade reduced data, and pipeline products would all be desirable.

8. References

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Science Reference Observation

Galactic Archaeology

Compilation lead by Carine Babusiaux

January 28, 2015

1 Abstract

This SRO covers Galactic Archaeology using high-resolution spectroscopy. This SRO combines inputs from the Feasibility Study, White Papers and "The Milky Way and Resolved Stellar Populations" Science Team group inputs.

2 Science Justification

The outer layers of the star atmospheres, accessible to spectroscopic studies, keep a fair representation of the mixture of elements present in the gas cloud out of which they formed. By determining those element mixtures, it is possible to "tag" stars with similar abundance patterns. Combining those tags with distances, kinematics and age information, it is possible to piece together the history of the Milky Way.

The science justification is already well developed in the Feasibility Study. Here is just a summary of the key science targeted:

- **Chemical Tagging of the Stellar Halo**. Tag in-situ formation halo versus accreted halo and quantify the relative importance of both process in the halo formation history. Tag different streams in the accreted halo by combining abundances, position and velocity patterns to constrain the accretion history[1] as well as the Galactic Potential (including dark matter). Detailed analysis of the metal-weak tail of the halo MDF which has a direct bearing on models for the formation of the first stars (See also the SRO on metal-poor stars).
- **Evolution of the Galactic Disk**. Tag thick disk versus thin disk, halo and bulge: determining the origin of the thick disk and its connection to the other Galactic components is intimately connected to the bigger question of how galaxies form and evolve. Tag the outer disk versus inner disk : model its formation history and its degree of inhomogeneity[2]. Quantify the signatures (both chemical and dynamical) of the on-going perturbations of the disc, such as the spiral arms or the central bar and their back reaction[3]; link the ISM and the stellar disc structure (See ISM SRO). Study how clusters form and dissolve to form the Galactic disc; see, by chemically tagging them, how much the debris of disrupted clusters is spread in galactocentric radius by the radial migrations.
- **Formation of the Galactic bulge**. Tag primordial bulge versus secular bulge and quantify the relative importance of both process in the bulge formation history; tag bulge

[1]WhitePaper The accretion history of the Milky Way halo through chemical-tagging, G. Battaglia
[2]WhitePaper Galactic archeology : The outskirts of the Milky Way disk, Haywood & di Matteo
[3]WhitePaper Milky Way structure and evolution, A. Siebert

Table 1: Outstanding differences between a 4m and a 10m on Galactic Archaeology.

	main traceur	G<17	G<20	MSE unique science case
Outer Halo	RGB tip distance?	80 kpc	315 kpc	halo accretion history
Outer Disk	Turn-Off distance?	3 kpc	12.5 kpc	Age studies of the outer disk
Bulge	Spectral Type at 8 kpc?	Red Clump	Turn-Off	Age studies of the bulge

versus thin disk, thick disk, inner halo to differentiate them (all stellar populations having their maximum density in the bulge area, including the first stars) and study common star formation histories[4]; detect substructures (in position + kinematics + chemistry space + age) as relics of the inner Galaxy formation / accretion history.

However our vision of the Milky Way as described above will most likely change in the coming years, and in particular in the post-Gaia area in which MSE will start its operation. We may learn that the Galaxy is not an equilibrium figure and that the different components are not that easily separated. Migration/scattering or cataclysmic event (bar onset, merger) has blurred out the different components with cosmic time, at least at some level. This is why we are discussing here about "tagging" (allowing to distinguish detailed SFH differences and streams) and not just "labbeling" a finite set of stellar populations.

For all those science cases the observation of a very large number of stars is crucial as we need to dissect the Milky Way along a very wide range of parameters and trace rare objects such as first stars.

MSE is the only instrument planned able to observe in high-resolution millions of the faintest Gaia stars. The scientific outstanding differences between the planned 4m surveys and MSE just by the increase of the mirror size are highlighted in table 1. We will see below that an increase in resolution compared to the planned surveys WEAVE/4MOST/MOONS operating at R=20000 would make the jump of MSE not only in magnitude but also in the parameter space probed by increasing the number of r and s-process elements and allowing accurate spectroscopic age determinations.

MSE will operate after the final release of the Gaia data, during LSST operation, and will be built on the experience of other wide-field spectroscopic surveys. It will therefore have all the ingredients at end to give an answer to all our current and future questions about the composition, formation and evolution of the Milky Way.

3 Key astrophysical observables

Key measurement of the source spectrum: Vr, $v \sin i$, Teff, logg, micro-turbulence, [Fe/H], [α/Fe], r and s-process elements (see Fig. 3).

Accuracy of those measurements: Vr $<$ 2 km/s to match Gaia transverse velocity accuracy (see Fig. 17 of the Feasibility Study). Atmospheric parameters (Teff, logg, micro-turbulence, $v \sin i$, [Fe/H]) as accurate and as uncorrelated as possible: those determine the accuracy of the abundances and are used to derive spectroscopic distances and ages. An error of 0.1 dex in logg for a turn-off star leads to a spectroscopic distance error of 10%. An error of 0.1 dex in logg and 100 K in Teff for a turn-off star leads to a spectroscopic age error of 30%.

Concerning the abundances, we want to identify populations separated by less than 0.2 dex (see Fig. 1). We therefore need [X/Fe] $<$ 0.1 dex. The higher the precision, the finest will be the separation between populations on a widest range of metallicity. As a example, Nissen & Schuster (2010) obtained a relative precision of $<$0.04 dex for [α/Fe] with a resolution R$>$40000 and SNR$>$150 on metal-poor dwarfs.

[4]WhitePaper Bulge science with MSE, Haywood & di Matteo

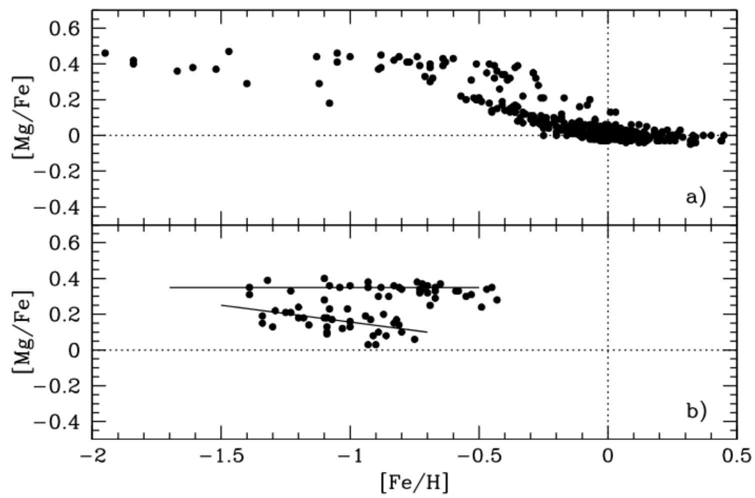

Figure 1: Fig 1 of Lindegren & Feltzing (2013). Fe and Mg abundances for stars in the solar neighbourhood. a) Fuhrmann data showing the two distinct thin and thick disc sequences (Fuhrmann 2011). b) the two high and low-α halo star sequences identified by Nissen & Schuster (2010).

Information extraction: Vr and $v \sin i$ by cross-correlation with templates, atmospheric parameters via maximum likelihood with stellar templates, EW measurements.

Successful measurement depends on:

- high spectral resolution (> 20000). Line blending, in particular in metal-rich stars, makes it difficult to perform accurate measurements of weak lines of most of the n-capture elements at R=20000, pushing towards higher resolution. To reach [X/Fe] < 0.1 dex, we actually need R=40000.
- high signal-to-noise ratio (>25)
- large wavelength coverage (needed not only to get abundances of several interesting elements but also to have less correlated atmospheric parameters)
- stable wavelength calibration
- good sky absorption / emission removal possible
- multi-epoch measurements to detect binarity

4 Target selection

A key point for the target selection of a Galactic Archaeology survey is the homogeneity and reproducibility of its target selection. The target selection should be simple and constant enough through time so that it can be easily reproduced and modelled for a proper study of completeness and target selection bias.

Source of photometry Gaia should be able to provide all targets for high resolution mode of MSE as it will be complete up to $G = 20.$ and will have a magnitude limit $G > 20.3$.

Other photometric surveys that could be used include Pan-STARRS 3π, Subaru/HSC, LSST, Euclid.

Target luminosity See discussion below on the trade-off between numerous (faint) stars and brighter stars but with higher resolution and/or SNR. Main targets for the HR survey will be Gaia stars ($G < 20$) without Gaia-RVS observations ($G > 13$).

The highest resolution and SNR is needed for stars for which one can derive accurately their distances to be able to study their origin through their 6D phase-space position. Note that the higher the logg accuracy, the higher the accuracy on spectrometric distances will be. At $G = 17$ a Gaia turn-off star will have a Gaia parallax accuracy of $\sigma_\pi/\pi = 20\%$ at 3 kpc. At larger distances, dwarfs will have to rely on spectroscopic distances. Dwarfs and sub-giants for which we can derive age estimates will be primary targets. At G=20 a turn-off star can reach 12.5 kpc (without extinction) allowing to study the outer disk. Standard candles such as stars from the horizontal branch and red giant branch tip can reach the outer parts of the Milky Way (80 kpc at G=20 for horizontal branch stars and 315 kpc for red giant branch tip without extinction). $G > 16$ is needed to reach the bulge red clump stars in low extinction regions such as Baade's Window. To study the bulge turn-off stars and derive spectroscopic ages, G=20 is needed.

Gaia will provide spectrophotometric estimates of stellar parameters as well as variability information, enabling a detailed (while still simple and uniform) target selection including standard candles.

Source density See Fig. 2. At G=20 the sky density at the Galactic Poles is around 1500 stars/deg^2, meaning largely enough targets to be observed with SNR>20 in less than 1h with 800 fibres according to the Feasibility Study numbers.

Total number of science targets required See Lindegren & Feltzing (2013) for a discussion of the trade-off between high precision on abundances and high number of stars. According to their model (see also their hypothesis), to distinguish 2 populations separated by 0.1 dex with an accuracy on the abundances of 0.05 dex one needs, as a lower limit, N=3000 stars. We want here to study different (or not!) populations: thin disc (young and old, inner and outer), thick disc, halo (inner and outer), bulge (primordial and secular). We will want also to study the variations of those populations within the Milky Way (e.g. abundance gradients) to study their formation mechanisms (e.g.. inside-out formation, radial migration...). We therefore want to study various "bins" in 3D position, age, metallicity and velocities. The good news is that those parameters are correlated. But we don't yet understand very well the dynamical state of the Milky Way and therefore what the best 6D phase-space "bins" should be in particular, and those request a very large amount of stars to be probed. Gaia in combination with MSE will make all the difference on this question. We can therefore hope that several million stars should indeed allow to disentangle the main formation scenarios.

5 Cadence and temporal characteristics

Repeat observations are required to detect binarity. They also allow observation of variable stars (15' max to accommodate delta scuti stars, which are about half of the variable stars that will be observed by Gaia), to accommodate transient follow-up[5] and eventually to observe more bright stars (bright stars need less integration time and could be swapped from one OB to the next).

Note that binarity detection is not only interesting by itself (see the SRO on stellar astrophysics), but is also needed as their non-detection can bias both the abundances determinations and the radial velocity dispersion. Erspamer & North (2003) tried to estimate the effects on the chemical abundances of a wrong continuum placement due to undetected duplicity and showed for example that for a V sin(i) of 10 km/s the bias can reach 0.1 dex. Concerning radial velocities, the effect of the un-detected binary orbital velocity on top of their systemic velocity can

[5]WhitePaper Opportunistic Transient Targeting, P. Hall et al.

increase by about 9 km/s the velocity dispersion of the population they belong to.

6 Calibration Requirements

1. Wavelength calibration accuracy and stability: high requirement. Both for multi-epoch observation (needed for multiplicity assessment) and for abundances determined by differential analysis (see next section).

2. Sky subtraction and Telluric absorption model accuracy: high requirement. Reached either with respectively sky and early-type stars observations and/or by sky emission and telluric absorption models [6]

3. Flux calibration: not a design driver.

Atmospheric parameters calibration will require observation of calibration stars. In particular a set of stars observed at different resolution modes will be needed to ensure a consistent output. Observations of clusters are very efficient for those kind of calibrations.

7 Data processing

1. Wavelength calibration, sky subtraction, telluric absorption model.

2. Spectra normalisation, Vr and $V \sin i$ measurement, stellar atmosphere parameters determination (the best being those 3 done at the same time by a maximum-likelihood technique).

3. Binarity assessment.

4. EW measures or adjustment of line profile to stellar model: abundances determinations

   The very large sample of stars studied by MSE will also allow the usage of large scale differential analysis. Indeed the accuracy of elemental abundances depends on a number of physical effects that are not always well-modelled (NLTE effects, 3D geometry, errors in loggf values...). By focusing on stars with similar stellar parameters, in a well defined logg/Teff region, and adopting a specific analysis method (Smiljanic et al. 2014), differential analysis can be performed and allows to reach very high precision in the separation of populations. It imply that the same type of target selection, observations and data analysis should be performed for high-resolution observations of the Local Group to enable detailed comparison, in particular with dwarf galaxies as potential building blocks of the Milky Way.

8 Any other issue

[6] http://ether.ipsl.jussieu.fr/tapas/

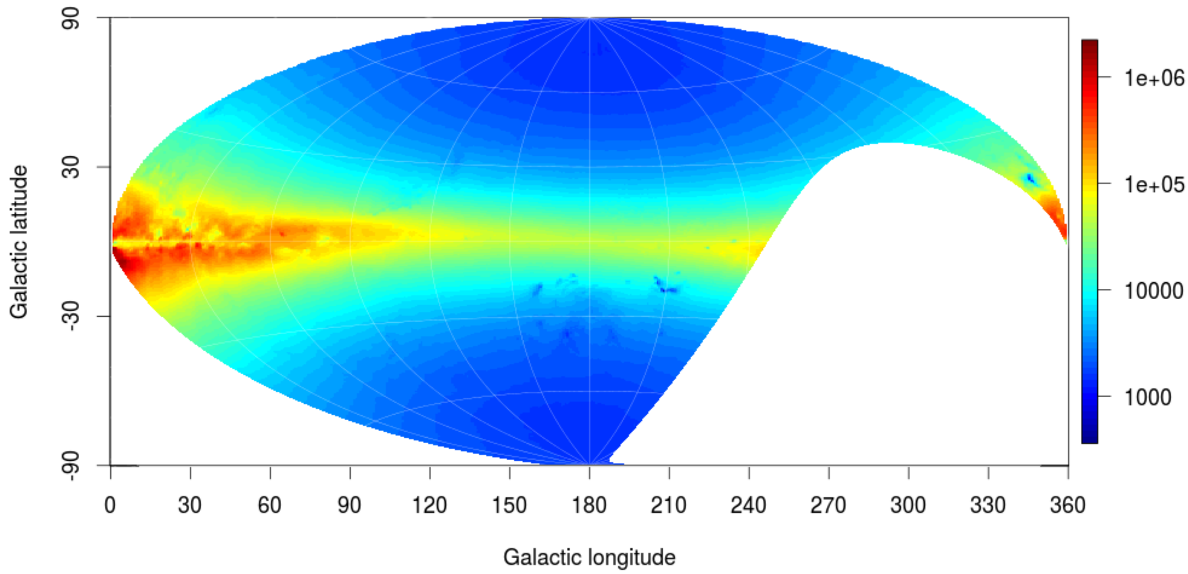

Figure 2: Sky density (per deg^2) up to G=20 visible from MSE ($\delta > -30°$), aitoff projection. Input data credit: Gaia DPAC CU2.

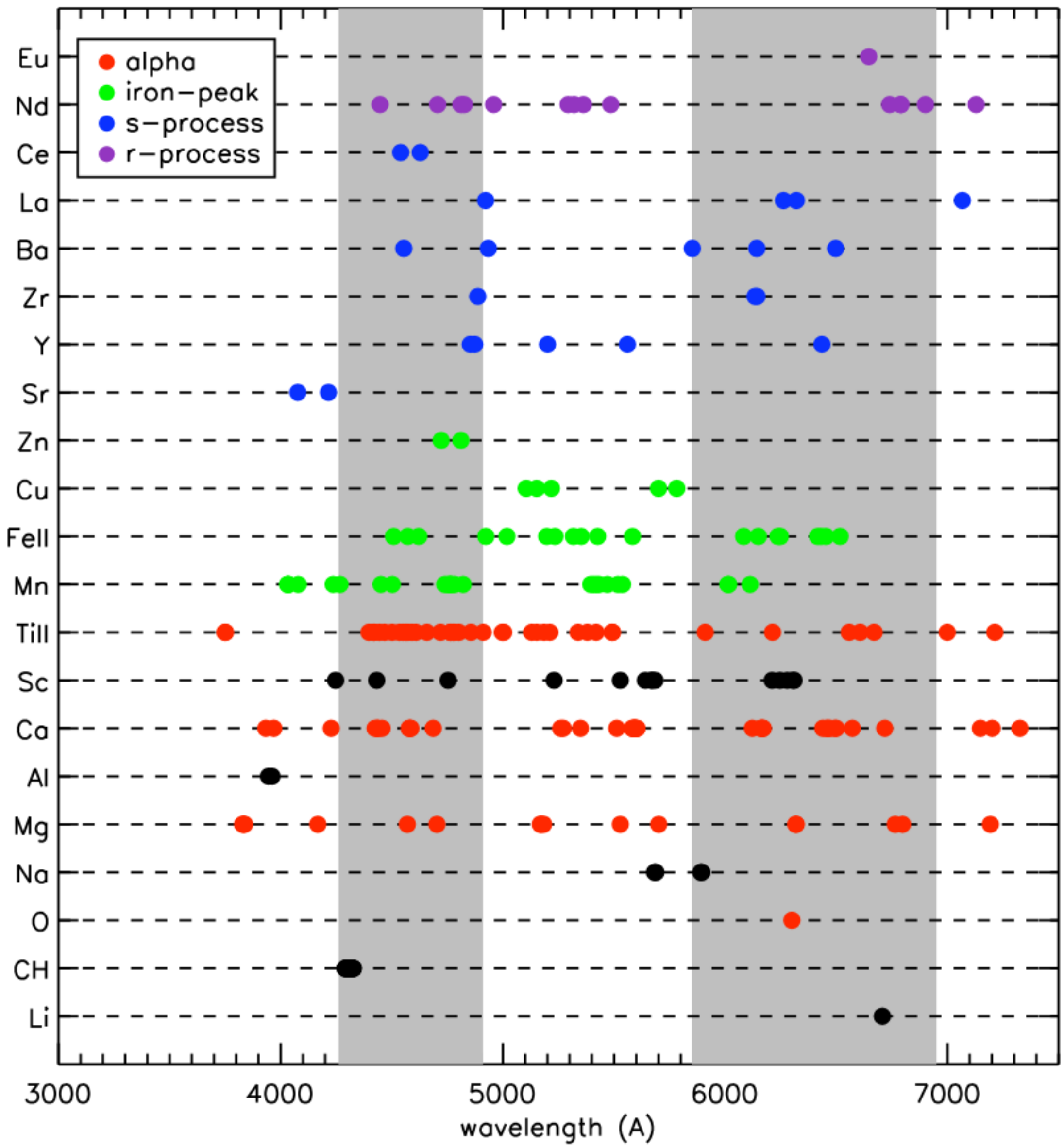

Figure 3: Fig from the Science Feasibility Study. Schematic representation of the spectral diagnostics available for various elements in the Galactic Archaeology Survey. These diagnostics are based on a synthetic metal-poor red giant spectrum; the available diagnostics will of course depend on the exact stellar target. Individual elements have been colour coded according to primary formation route: i.e., alpha, iron-peak, s- and r-process elements. The grey regions show the blue and red windows proposed for the HR mode.

MSE Science Reference Observation

STREAM KINEMATICS AS PROBES OF LCDM LUMPS

1. Abstract

2. Science Justification

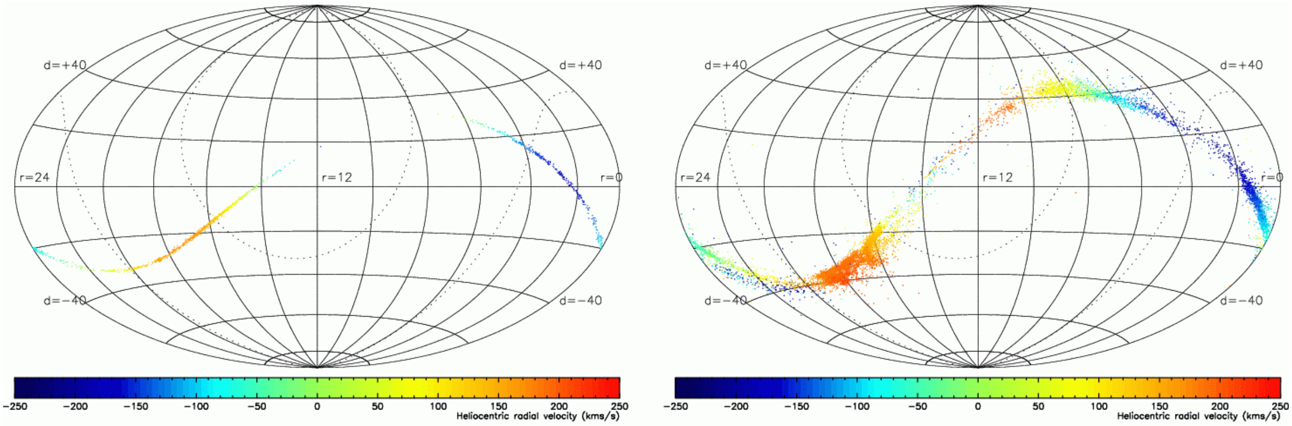

Figure 1: *The effect of dark matter halo sub-structures on low-mass star streams (Ibata et al. 2002, MNRAS 332, 915). In a smooth halo (left panel), low-mass stellar streams follow narrow paths on the sky, confined to a narrow range in distance and velocity (shown in colour). In the presence of dark matter substructure (right panel), the potential becomes uneven and the stream path and velocity structure become complex. With Gaia, such studies will now finally be within reach.*

Cold dark matter cosmology predicts that galaxies contain hundreds of dark matter sub-structures (Klypin et al., 1999) with masses similar to dwarf satellite galaxies. Only a small fraction of these dark satellites can be identified with the observed population of satellites, however, which raises the question of where the missing satellites are. A large body of theoretical work has demonstrated that it is possible to hide the vast majority of dark matter satellites by having their baryons expelled during the era of reionization (see, e.g., Kravtsov 2010, AdAst 2010, 8, and references therein). However, it remains a fundamental prediction of LCDM theory that the dark matter clumps exist in large numbers. Possibly the best means to test this prediction is to examine the dynamical influence of such structures directly in nearby galaxies where we possess the richest datasets. Indeed, Ibata et al. (2002, MNRAS 332, 915) showed that massive dark satellites can strongly perturb fragile structures such as stellar streams. The halo substructures change the host galaxy from a smooth force-field in the absence of CMD lumps (left hand panel of Figure 1) into a “choppy sea” where the stream and its progenitor are tossed hither and thither (right hand panel of Figure 1). The effect of this is that the stream becomes dynamically heated, with a significantly larger line of sight dispersion, velocity dispersion, and width. Indeed, this is even more striking in energy and angular momentum space (see Ibata et al. 2002), which will finally be accessible in the MSE era. Finding even a single unheated ancient globular cluster stream would disprove the existence of CDM structures of mass $< 10^7$ Solar mass, and would place unprecedented constraints on granularity on these scales.

The globular cluster stream of highest contrast that is currently known is that of Palomar 5, which is a structure that can be seen directly in SDSS star-count maps of blue point sources (see Figure 2). However, even for this most favourable of objects, only a handful of stars in the stream are bright enough to be detectable by Gaia (the main sequence turnoff lies at g=20.2). Thus it is very unlikely that with Gaia alone we will be able to detect many distant halo streams, and examine their kinematics. Clearly this is also beyond the capabilities of surveys undertaken on 4m-class telescopes.

However, MSE will allow us to solve this problem. New stellar streams may be found directly in large MSE spectroscopic surveys, or indeed by following up candidate structures found for instance with Euclid or LSST photometry. As with Palomar 5, it is likely that (post-facto) a few giant-branch members can be associated to Gaia stars with proper motion measurements, which would provide an accurate orbit for the detected stream.

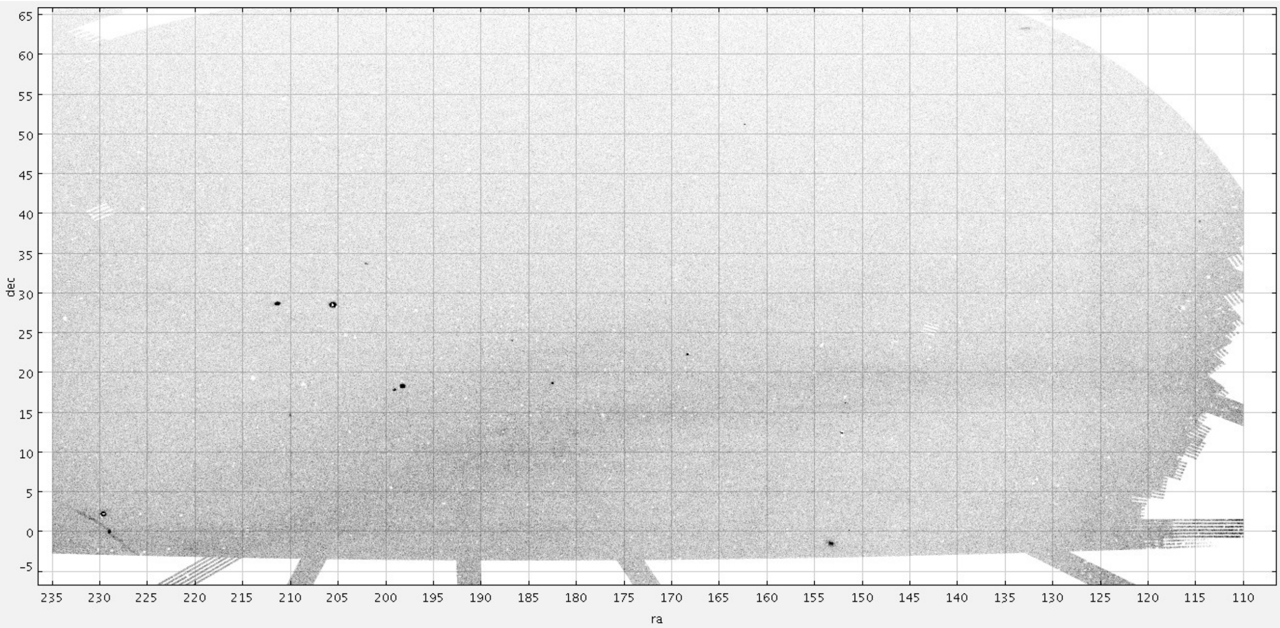

Figure 2: *Main sequence turn-off stars with 0.1<g-r<0.4 in the North Galactic Cap, observed by the SDSS. The highest contrast stream here is that of Palomar 5, seen in the bottom left-hand corner.*

Some of the substructures one may find in cold streams may be induced by epicyclic motion of stars in the tails (Küpper et al. 2008, MNRAS 387, 1248; Mastrobuono-Battisti et al. 2012, A&A 546, 7). and thus clumps themselves are not necessarily the signature of dark subhalos. The key to understanding these structures is a careful modelling of their morphology and kinematics. N-body simulations in the presence of a large population of expected CDM mini-halos show that there will be localised heating of the globular cluster stream stars by typically 10 to 15 km/s over and above the intrinsic velocity dispersion of the stream (which in the case of Palomar 5 is <5 km/s, Dehnen et al. 2004, AJ, 127, 2753) due to encounters with the larger dark structures. The spatial scale over which the increased dispersion will be present depends on the physical size of the biggest structure that has heated the stream, but scales of ~1 kpc are plausible.

In addition, if CDM is correct, there will also be heating due to the hundreds of smaller dark matter structures that will make the Galactic potential locally quite irregular. With the mini-halo mass function adopted in Ibata et al. 2002, these cause a heating of the stream of ~5 km/s/Gyr, so that the velocity dispersion will increase approximately uniformly with distance along the tidal tail.

Finding even a single unheated long stream would provide incontrovertible proof that dark matter is smooth on small (sub-galactic scales), while discovering evidence for heating by dark clumps would be a vindication of the existence of the dark structures and a triumph for dark matter theory. Either result would be a legacy for MSE.

3. Key Astrophysical Observables

The key observables are stellar radial velocities capable of resolving the internal dynamics of a stream (accuracy of ~1 km/s is required). However, additional spectroscopic metallicity information would be extremely useful for population discrimination.

4. Target Selection

As mentioned above, some streams will undoubtedly be discovered by LSST, Euclid and Gaia, and their kinematic follow-up can be undertaken with a massively multiplexed spectrograph like MSE. However, low-contrast stellar streams will be detectable purely from kinematics. This project therefore requires the measurement of the radial velocity of the largest possible number of stars, in order to detect the relatively low contrast stream structures. The most interesting streams will be those that inhabit the halo (say R> 25 kpc) beyond the perturbing influence of the Galactic disk.

5. Cadence

Repeat observations over a period of a few weeks to a few months would be extremely useful to identify binaries in the streams, which would otherwise lead one to deduce a spuriously high velocity dispersion.

6. Calibration

Simple wavelength calibration is sufficient.

7. Data Processing

Standard processing should be sufficient.

Dynamics and chemistry of the Local Group dwarf galaxies

1. Abstract

With the MSE, we will be able to conduct a systematic survey of the kinematics and chemistry of Local Group dwarf galaxies within 1 Mpc with a level of detail that has never been achieved before and cannot be achieved anywhere else. Dwarf galaxies are the most dark matter-dominated systems known, and for this reason, it is widely assumed that their stars can be used as a straightforward tracer of their overall potentials. Because these potentials should be close to the predictions of dark-matter-only numerical simulations, the dynamics of stars in dwarf galaxies can test the behavior of dark matter on sub-kpc scales in collapsed objects. A systematic survey of all dwarf galaxies down to L~10^3 Lsun will yield the details of their potential (cusped? cored? NFW-like? compatible with modified-gravity theories?), of their extent and whether they are shaped by tides (what is the impact of their environment?), of their chemical abundances and spatial structure therein (are they pristine or complex systems), and of their earliest star formation through their most metal-poor stars (where they shut down by reionization?). A systematic spectroscopic survey of Local Group dwarf galaxies is the key to understanding the faint end of galaxy formation and evolution.

2. Science Justification

Intensive spectroscopic surveys are required to advance our understanding of dwarf galaxy dynamics in a meaningful way and thereby unveil the properties of the dark matter subhalos they inhabit. Recent efforts to systematically gather large, sub-km/s-uncertainty radial velocity samples for nearby dwarf galaxies have shown the power of data sets of a few thousands of spectra for a single system (Walker et al. 2009). However, as the dynamical modeling of these systems improves, these data sets are also now showing their own limitations and the necessity to gather information beyond the mere velocity of the systems and into the realm of chemical abundances (see Walker & Peñarrubia 2011 vs. Strigari et al. 2014). At the moment, large uncertainties remain on the properties of their dark matter halo/ potential (cored/cusped, extent, implied dark matter density), the presence of stellar substructures in the dwarf galaxies (remnants of dwarf/dwarf mergers?), and the presence of extra-tidal stars that would hint at systems strongly affected by the presence of their host.

The MSE would bring about an entirely new era for such studies, enabling accurate kinematic measurements like this to be performed *much* more efficiently, over the full range of dwarf galaxy luminosities ($10^{3–7}$ L_{sun}), with at least an order of magnitude more stars in each system, and well beyond the peak of the rotation curve, from *all* Local Group dwarf galaxies with $\delta > -30^{\circ}$. Furthermore, the high multiplexing and large field of view of MSE would enable efficient spectroscopic variability surveys of the fainter half of the Local Group dwarf galaxy sample ($<10^5 L_{sun}$) so as to robustly tackle the growing concern that binaries mat significantly affect the low velocity dispersion measurements of these systems, thereby questioning the outcome of their mass modeling based on single epoch data. Crucially, the MSE would also be well-positioned to understand how the dynamics of dwarf galaxies respond to evolutionary effects, in particular tidal stripping, due to its ability to explore sparse outer fields while ensuring high completeness in the presence of strong contamination.

The samples gathered with the MSE will have the power to constrain the formation and evolution of the sample of ~70 dwarf galaxies within the Local Group, the only satellite systems that can be observed in such detail. Most of these satellites will not have been studied systematically before the MSE comes online, owing either to the faintness of the target stars beyond ~100 kpc and the inability of upcoming 4m-telescope surveys to observe them, or to the lack of survey facilities on 10m-class telescopes, necessary to conduct a systematic survey.

Furthermore, connecting the dynamics of dwarf galaxies to their metallicities and chemical abundances is a key area of current research and will likely remain so, well into the era of the MSE. Indeed, there are at least three important open questions regarding the chemistries, metallicities, and star formation histories of dwarf galaxies that would take advantage of a highly multiplexed, wide-field instrument on a 10m telescope:

- The full metallicity distribution, including spatial gradients in metallicity and/or stellar populations. This would provide important information on whether star formation propagated inwards or outwards and whether dwarf/dwarf interaction have a significant role in heir formation/evolution. These data would also indicate if there were significant metallicity variations with time, and would make it possible to break the age-metallicity-reddening degeneracy definitively in color-magnitude diagram studies.

- The dispersion in abundance ratios at fixed metallicity: e.g., the patterns of [α/Fe] vs. [Fe/H] and the relative proportions of other element groups in relation to the iron-peak elements (i.e., light elements, odd-Z elements, light and heavy s-process, r-process). These abundances hold important clues to the history of star formation in these galaxies as well as their initial mass function.

- A census of rare stellar species (extremely metal-poor stars, carbon stars, etc), including their overall numbers and spatial distributions.

As an illustration of the sheer power of ngCFHT for chemodynamical studies of nearby dwarf galaxies we consider NGC 6822, one of the nearest dwarf irregular galaxies — at an "intermediate" distance for Local Group galaxies (~500 kpc). It is one of the more intriguing targets for detailed study because of ongoing disturbances in its HI velocity field and very active star formation. There is some evidence for young stellar populations associated with infalling HI clouds, and for deviations from circular disk rotation. However, the large angular scale of the system (~ 1 degree across) and the likelihood that the substructures are represented by only a small fraction of the stars means that the system remains poorly understood, even with a small (but steadily growing) sample of stellar spectra from VLT/FLAMES and Keck/DEIMOS.

It is, however, worth noting that it has already been demonstrated that the largest practical samples from Keck/DEIMOS and VLT have not been enough to identify the population substructures or true dynamical state of galaxies like NGC 6822 (Kirby et al. 2013, 2014). Even smaller/apparently simpler galaxies like WLM still have large uncertainties (e.g. Leaman et al. 2013). A very interesting analogue could be to the Small Magellanic Cloud, where the structure is only now becoming apparent based on spectroscopic samples of several thousand stars (e.g., Dobbie et al. 2014a, 2014b). Obtaining thousands to tens of thousands of spectra is these dwarf galaxies is therefore a necessity to understand dwarf galaxy structure and evolution.

With MSE, tens of thousands of member stars spanning all ages could easily be observed with multiple fiber set ups of a single pointing. It would therefore be possible, for example, *to measure radial velocities accurate to better than 5 km s^{-1} for every AGB and red supergiant star, and nearly all RGB stars within 1.5 mag of the TRGB, in just a handful of MSE nights at medium resolution and with S/N ~10–20*. For bright member stars, repeated observations over a period of several years would allow unprecedented studies of variability and evolutionary changes for stars in the late phases of evolution.

Closer to us, all observable stars of the recently found and most dark-matter-dominated, faint Milky Way dwarf galaxies could be targeted with a single fiber configuration but with a monthly to yearly cadence to consistently study spectroscopic variability (e.g. Koposov et al. 2010, Martinez et al. 2011). For more extended/brighter systems, the possibility to probe down to the oldest main sequence turn off will allow for an exquisite modeling of their potential with thousands of potential targets, but also enable a systematic search for the stellar extent of the dwarf galaxies, combined with a search for extra-tidal stars, similarly to what has currently only been achieved for a single dwarf galaxy (Carina; Muñoz et al. 2005), but on a much larger sample and scale.

3. Key astrophysical observables

Radial velocity measurements to study the dynamics of dwarf galaxies in the Local Group usual rely on a small set of strong lines in the spectrum, typically the Calcium triplet lines at ~8500 Å. Velocity uncertainty requirements vary with targets but are typically <1–2 km/s, which is achievable within 1–4 hours down to i~22.5, or S/N~5–10 with the medium resolution grating.

The Calcium triplet has the added advantage of also being a well-understood [Fe/H] indicator, inasmuch as spectra are observed with S/N~20.

For abundances analysis, the requirements are similar to those of the chemical tagging project of the Milky Way SRO.

4. Target selection

The depth reached by current panoptic surveys (SDSS, Pan-STARSS1; *i*~22.5) are well tailored to the needs of dwarf galaxy kinematic and chemical abundance surveys of Milky Way dwarf galaxies, but could be supplemented by wide field but deeper, targeted photometric surveys. Such observations are already available from public archives in most cases and reach 2–4 magnitudes deeper, more than enough for the requirements (e.g. targeting of the Andromeda dwarf galaxies that will use data from the CFHT large program PAndAS).

The source density of potential targets ranges from a few tens for the further/faintest dwarf galaxies, to tens of thousand per MSE pointing for a handful of close-by and bright Milky Way satellites. Most targets will have target densities in the hundreds to a few thousands range, perfectly tailored to the MSE set up.

The possibility to observe some targets with the medium-resolution grating for velocities and [Fe/H] measurements *and,* for a smaller sub-sample, the high-resolution grating for chemical abundance measurements of the brightest targets (à la FLAMES with GIRAFFE and UVES) would be strongly beneficial to this program.

Given the wide variety but reasonably limited sample of Local Group dwarf galaxies, this program should strive to observe all known Local Group dwarf galaxies (~70 targets). Observing strategies should be tailored to the a specific regime of dwarf galaxies but should range from a few hours to a few nights per target over a period of ~5 to 10 years.

5. Cadence and temporal characteristics

A temporal survey of dwarf-galaxy-member stars will be essential to constrain their binary population and how it impacts on the modeling of their dark matter potential. This is particularly important for the fainter half fo the Local Group satellites. Little is known about their binary population of dwarf galaxies but observations have shown that variation can be presence on time-scales of months (Koposov et al. 2011) but binaries with periods below ~10 yr can likely bias velocity-dispersion measurements (McConnachie & Côté, 2010). Therefore, at least some configurations should be observed anew on both monthly and yearly timescales. An appropriate statistical modeling of the repeated observations means that only a handful of repeats are required for a given configuration.

6. Calibration requirements

Wavelength calibration should be able to yield sub-km/s velocity accuracy over different configurations and repeated observations over yearly timescale.

Efficient and accurate sky subtraction is also needed for the chemical abundance part of the program.

Flux calibration is not a significant issue for this program

7. Data processing

Straightforward and now common procedures to go from observations to velocities, [Fe/H], and their uncertainties, further tested for systematics from repeat measurements of bright stars.

Measurement of abundances from the spectra are only now entering the large-sample era but pipelines will be in place to also straightforwardly yield abundances by the time the survey starts (see e.g. on-going efforts with the HERMES survey).

A chemodynamical deconstruction of M31 & M33

1. Abstract

Gaia is gathering unprecedented astrometric measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy. Radial velocity measurements and chemical information will also be provided by onboard instruments. This dramatic advance in our ability to map the six-dimensional phase-space structure of a galaxy will likely usher in a "Golden Age" of Milky Way research. However, although Gaia will provide a very detailed view of the structure and dynamics of our Galaxy, this information will have to be put into context by comparing the results with observations of other galaxies. Without this essential complementary information, any conclusions that we may draw about the process of galaxy formation from observations of the Milky Way would be premature. It is in this context that we propose to conduct the ultimate chemodynamical decomposition the other two Local Group spirals (M31 and M33) with the MSE. These galaxies represent the obvious stepping stones between our highly detailed description of the Milky Way, and the low-resolution studies of more distant galaxies, in the realm of a few Mpc and beyond, where we can obtain significant samples of galaxies (as a function of galaxy type, environment, mass, etc).

2. Science Justification

The MSE will provide a unique opportunity in this time-frame to make a pivotal contribution to the subject by undertaking a large spectroscopic and systematic survey of these two Local Group galaxies. The goal would be to obtain a statistically significant sample of stars belonging to their constituent structural components. The scientific aim of this "Galactic archaeology" theme is to understand the galactic formation process, which is clearly an open-ended endeavour. Our power to address the key issues (e.g., thick disk formation, halo formation, streams, chemical enrichment history), depend on the spectral resolution that the survey affords. In the Milky Way, current state-of-the-art spectroscopic surveys (e.g., RAVE, Gaia-ESO, HERMES) aim to sample of order one million stars. This is feasible with a reasonable allocation (i.e., a few months) on MSE. In contrast to the very local (few kpc) view provided by RAVE and others, this proposed M31/M33 study would provide a uniquely powerful, global panorama of these galaxies, out to the farthest reaches of their stellar halos.

Current photometric surveys, complemented with small spectroscopic samples have revealed the very structured nature of the M31 inner halo (Ibata et al. 2005), all the way out to its farthest reaches (Chapman et al. 2006, Gilbert et al. 2013, Ibata et al. 2014), where the left-overs of past dwarf galaxy accretions can be seen as stellar streams of varying width, metallicity, and distances. M33 itself appears to have its stars pulled out of its disk through tidal forces of its host (McConnachie et al. 2009). However, a qualitative comparison with expectations from galaxy formation in a LCDM universe is currently made very difficult because of the mainly two-dimensional view we have of the M31 and M33 surroundings (e.g. Font et al. 2008). It is therefore essential that the community gathers a systematic census of additional properties (radial velocities, metallicities, alpha-abundances) on a large sample of

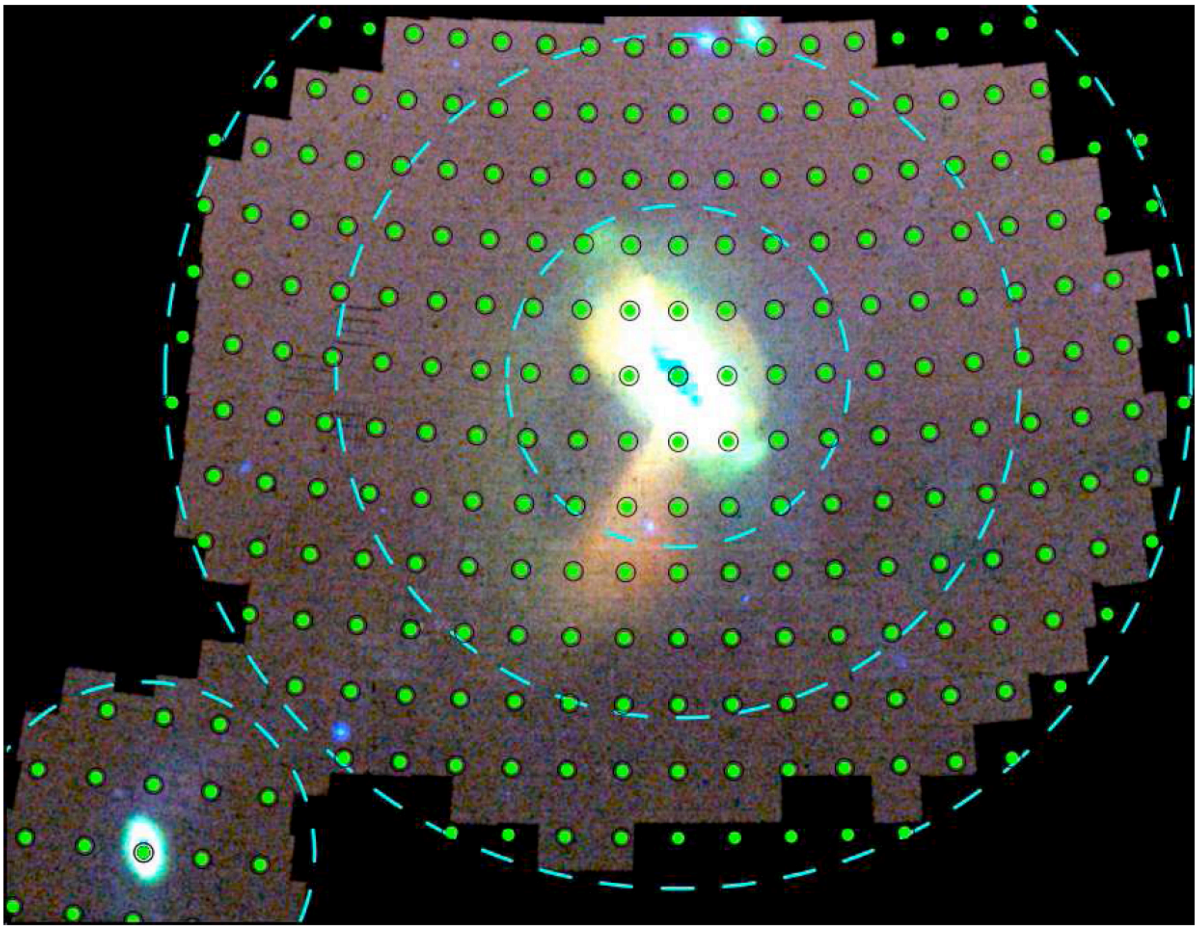

Figure 25: Spatial distribution of candidate RGB stars in the environs of M31 and M33, as identified from colour-magnitude cuts from the CFHT/MegaCam PAndAS Large Program. Dashed circles highlight maximum projected radii of 50, 100 and 150 kpc from M31, and 50kpc from M33. Filled dots indicate *the central coordinates* (not the FOV) of MSE pointings that would give complete areal coverage of the M31/M33 system.

member stars so the true picture of these two galaxies and their hierarchical history can be put together.

The figure above shows the spatial distribution of candidate red giant branch (RGB) stars in the environs of M31 and M33, as identified by colour-magnitude selection from 400 deg^2 of contiguous *gi* imaging with CFHT/MegaCam as part of PAndAS. Color-coding corresponds to the color of the RGB stars, such that redder RGB stars (likely higher metallicity) appear red, and bluer RGB stars (likely metal-poor) appear blue. Dashed circles correspond to maximum projected radii of 50, 100 and 150 kpc from M31, and 50 kpc from M33. PAndAS resolves point sources at the distance of M31 (D = 783 kpc; McConnachie et al. 2005) to $g \approx 25.5$ and $i \approx 24.5$ at S/N ~ 10. PAndAS therefore reaches down (nearly) to the horizontal branch level, providing photometry of sufficient depth that potential spectroscopic targets for a 10m facility could be selected. In the figure, the effective surface brightness of the faintest visible features is of order 32–33 mag $arcsec^{-2}$. This corresponds literally to a few RGB stars per square degree. Note that the disk of the Milky Way is located to the North so there is increasing contamination in the colour-magnitude of the RGB locus by foreground dwarfs; the reddest RGB stars are particularly affected by this source of contamination. Young, blue stellar populations — and even intermediate-age populations such as asymptotic giant branch (AGB) stars — are not present in the outer regions of M31 in any significant numbers. Thus, any spectroscopic study of the outer regions of the M31 halo will necessarily concentrate on the older, evolved, RGB population. For this reason, we consider separately surveys of the *outer halo* (characterized by a low surface density of evolved, giant star candidates) and the *inner galaxy* (with a high surface density of targets from a mixture of stellar populations).

- **An outer halo survey of M31/M33:** This survey aims at obtaining a complete, magnitude-limited, spectroscopic census of every star in the outer regions (40–150 kpc) of an L* galaxy halo to provide complete kinematics for every star, supplemented by metallicity estimates for most stars and alpha-abundances for the brightest ones. Ultimately, such a survey will allow us to deconstruct a nearby galactic halo into its accreted “building blocks”. Such a survey will provide the ultimate testbed of the hierarchical formation of L* galaxies and further yield the optimal data set to constrain the dark matter content of M31 and M33.

- **Faint stellar populations in the inner regions of M31/M33:** This part of the survey focusses on the study of the disk/thick-disk/halo transition region to measure the extent of the disks, characterize the relationship between these components, and to determine the role of mergers in the disk and inner halo evolution.

3. Key astrophysical observables

This projects relies on gathering a very large sample of radial velocities for M31 red giant branch stars. The brightest RGB targets, observed at a higher S/N, will also yield [Fe/H] and, when possible, [α/Fe] measurements. Typically, observations are focussing on the Calcium triplet region at ~8500 Å as these strong lines have the benefit of yielding good velocities, even at marginal S/N, and they are also a good [Fe/H] estimator.

In order to properly sample the very low density regions of the halo, one needs to selects targets as far down as possible along the RGB. A good compromise between exposure time and depth is achieved by reaching 2–3 magnitude below the TRGB (*g*~24.5). With the medium resolution grating, 6h-long integrations will yield S/N~4 spectra for the faintest stars, from which velocities can be measured with ~15 km/s uncertainties. Such an accuracy is necessary to disentangle M31 halo stars from MW foreground contaminant and, more importantly, to decompose the M31 stellar halo in its “building blocks,” leftovers from the process of hierarchical formation. The brightest stars in the sample, with much higher S/N will be use used to derive reliable [Fe/H] and [α/Fe] measurements and, when the density of a stellar structure is high enough, its velocity dispersion. Tagging stellar structures via these properties will ensure it is possible to disentangle the properties properties and time of infall of the accreted satellites.

In the central regions of M31, thousands to tens of thousands of targets can be selected at the bright end of the RGB so the inner region survey can focus on bright targets within 1 mag of the TRGB for which 1-hour long observations will yield accurate kinematics (i.e., better than 5 km s^{-1}). The large density of sources however means that multiple configurations (up to ~10) for a given pointing are mandatory to maximize science.

4. Target selection

The PAndAS survey presented in the figure above is ideal for the target selection: it is deep enough to provide any stellar target we could wish to observe with a 10m telescope and its spatial extent (out to 150/50 kpc from M31/M33) is well tailored to study the stellar halo of M31 to large distances.

The source density of potential targets ranges from a few hundred candidate stars in the outskirts of the M31 halo (most of them MW foreground contaminant) to tens of thousand per MSE pointing for a handful of central fields.

All the observations will be conducted with the medium resolution grating.

The outer halo part of the survey would cover ~350 deg^2 if based on the PAndAS survey, which, with ~6h-long integrations per field and a 1.5-deg^2 field of view, requires ~150 nights of MSE time. In high density central regions (~40 deg^2), an average of 5 pointings with 1h integrations will require 15 nights. Thus, this project would require of order 165 nights to be complete. These can be spread over a period of 5–10 years.

Given the density and faintness of targeted stars, this science requires a wide-field, multi-object spectrograph on a 10m-class telescope and, as such, is a particularly good match to the MSE specifications.

5. Cadence and temporal characteristics

There are no particular temporal requirements for this survey beyond the necessity of some duplicate observations to ensure the stability of the system.

6. Calibration requirements

Wavelength calibration should be able to yield km/s velocity accuracy over different configurations and repeated observations over yearly timescale.

Good sky subtraction is also necessary to work reliable in the low-S/N regime of the faintest targets.

Flux calibration is not a significant issue for this program

7. Data processing

Straightforward and now common procedures to go from observations to velocities, [Fe/H], and their uncertainties, further tested for systematics from repeat measurements of bright stars.

Science Reference Observation

Exploring R > 90000 option for MSE
Compiled by Aruna Goswami

Rationale
With the advances and extensive efforts in the spectroscopic investigations with R $\sim$ 40 - 60K a fare picture of the bright universe has emerged in the last few decades; ongoing and planned efforts are expected to soon fill some remaining gaps. However, the faint universe remains an essentially unexplored frontier primarily because of lack of observational capabilities. While several proposed facilities will have the capability to look at the fainter universe, a major weakness may be insufficient accuracy to address details. The MSE is a proposal to replace the 3.6m CFHT with a 10m, dedicated spectroscopic survey telescope. The new facility with its combination of large collecting area, wide field of view, high multiplexing, range of spectral resolutions (R = 2000, 6500, 20000) will have the ability to perform panoramic, multi-object spectroscopy of the faint universe.

Given that there are many observatories around (some are being proposed and will be operational at about the same time as MSE) that are engaged in large sky surveys at R $\sim$ 20 to 45K, it seems more appropriate to aim for a substantial upgrade for a survey going up in the late 2020s. It can be expected that with the ongoing and near-future plans activities, most of the important studies in Galactic science in the reamls of 0.2 - 0.25 dex precision would be completed by 2020, although the somewhat routine task of creating larger samples would remain, unless the accuracy level is improved with studies at < 0.1 dex precision.

A major challenge in contemporary astrophysics is to understand the details of many important astrophysical processes like, production mechanism and production sites of r- and s-process elements, finer details of the Galactic structure, physical as well as chemical properties of exoplanets, internal dynamics of resolved stellar population etc. Abundance studies that can enable such investigations require accuracy at the level of < 0.05 dex for which high resolution is crucial. Such accuracy in abundance analysis is not possible to achieve with R < 90K. A multiplexed moderate resolution (R $\sim$ 50K) and a single object high resolution (R > 90000) spectroscopic facility for the entire 340 - 950 nm wavelength region is highly desirable in this context. In addition to large scale survey programs such a versatile instrument will enable precision spectroscopy for decades to come making it as one of the rare and critical facilities. Implementing such a capability would unavoidably entail some increase in complexity and cost; however, there are scientifically compelling reasons to explore this possibility.

2. Science Justification (Maximum 2 pages, including figures/tables/references/etc)
A number of outstanding questions in contemporary astrophysics can not be addressed adequately using most of the existing (and planed) facilities due to their inability to perform precision spectroscopy that require very high resolution combined with very high signal-to-noise ratios. For instance,
the nucleosynthetic origin of heavy elements
the time of contribution of the First AGB stars to Galactic chemical enrichment
'Li problem'
chemical properties of bulge stars
chemical properties of hyper-metal-poor stars that require abundance estimates from very weak

lines (in some cases < 10 mÅ)
characterization of transiting systems, requiring RV precision ~ 1 m/s, etc.

Answer to many such fundamental questions need accurate measurements at isotopic levels that require higher spectral resolution, R $>$ 90 K and high S/N ($\sim$ 200). Measurement of isotopic ratios however provides a completely new window into nucleosynthesis, mixing within stars and stellar evolution significantly improving our understanding of nuclear processes in various astrophysical sights.

The origin of heavy elements
Isotopes of elements are produced through specific nuclear reactions. Thus any neuton-capture element with multiple isotopes that are produced in different amounts by the s- and r-processes can be used to assess the relative s- and r-process contributions to the stellar composition. As the isotopic abundances for these elements are more fundamental indicators of n-capture nucleosynthesis, they can be directly compared to r-process and s-process predictions without the smearing effect of multiple isotopes. To reconstruct the origin and evolutionary history of neutron-rich elements in the Galaxy it is thus important to extend our study to the isotopic level. Accurate measurements of these abundances in an extended sample of extreme metal-poor stars (some are also expected to be detected from MSE survey) will provide new constaints on the origin(s) of heavy elements in the Galaxy.

It should be noted that the identification of precise astrophysical sites of the r-process and p-process still remains a challenging task.

The onset of AGB stars contribution to the Galactic chemical enrichment
High resolution capabilility of EMSE can be used to address a long standing question on the time at which the first low- and intermediate-mass stars had reached the AGB phase and began to contribute to the Galactic chemical enrichment with the products of nucleosynthesis. The knowledge of the epoch at which the AGB stars had begun to enrich the Galactic halo can help us to delineate the contribution of elements produced by low- and intermediate-mass stars from the contribution of elements produced by massive stars. Estimates of the Mg isotopic ratios, i.e., ^{25}Mg/^{24}Mg, and ^{26}Mg/^{24}Mg with respect to metallicity are particularly important in this regard because they provide clues to the nucleosynthesis history of the star, i.e., whether its isotopic pattern arises from pre-supernovae evolution of massive stars, or other processes such as the contribution from intermediate-mass AGB stars. The wavelength region 5134.6 Å 5138.7 Å and 5140.2 Å are usually employed to determine the isotopic abundance ratios of ^{25}Mg, ^{26}Mg to ^{24}Mg. An example is shown in figure 1. Laboratory Fourier transform spectroscope measurements of the isotopic ^{24,25,26}MgH lines are available in literature (i.e., Bernath et al. (1985), ApJ, 298, 375). High spectral resolution with high S/N observations of an extended sample of halo dwarfs will help constrain the estimates of appearance of AGB stars in the Galaxy and will be useful to better constrain the formation timescale of the Galactic halo.

Pb abundance as tracers of early s-process nucleosynthesis
At low-metallicities the pre-existing seed nuclei are comparatively less abundant; the available neutrons are numerous enough to convert all the seed nuclei into Pb and Bi. Low-metallicity AGB stars should therefore exhibit large overabundances of Pb-Bi as compared to lighter s-elements (Partial mixing of protons scenario accomapanying third dredge-up of Goriely & Mowlavi 2000, A&A 362, 599). Pb abundance is usually measured using the Pb I line at 4057.81 Å . High resolution $>$ 90K is required to separate the Pb I 4057.81 Å line from a CH

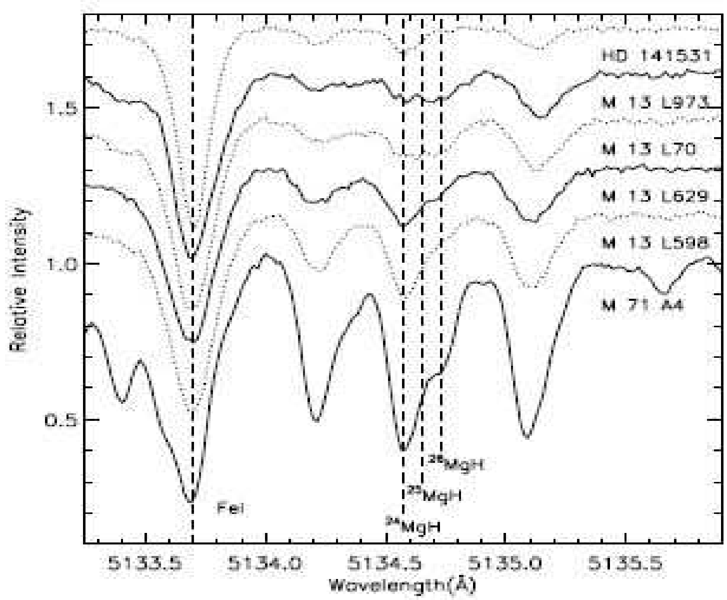

Figure 1: Spectra of Globular cluster stars in the wavelength region that includes the 5134.5 Å MgH line. The positions of ^{25}MgH, ^{26}MgH and ^{24}MgH lines are marked by vertical lines. This MgH line shows substantial asymmetries for M71 A4, M13 L70 and M1 L973 (Ref: Yong et al. 2006, ApJ 638, 1018).

line lying less than 0.1 Å bluewards (Figure 2). Measurement of Pb abundances in the Milky Way halo dwarfs as well as stars in Globular cluster and nearby galaxies will make important studies in this regard.

Li problem

Extremely high precision and high spectral resolution data are required to investigate the primordial nature of ^{6}Li from estimates of ^{6}Li/^{7}Li ratios. This remains a subject of raging controversy as in apparent contradiction to Big Bang nucleosynthesis theory, estimates in a small sample of extremely metal-poor dwarfs show detection of ^{6}Li at a ratio of $\sim$ 5% of the total Li in EMPs hinting at a primordial nature. This needs to be verified considering a statistically significant sample.

WMAP determination of the cosmic baryon density, combined with the Big Bang Nucleosynthesis (BBN) theory, tightly predicts a Li abundance value that differs from the value of 'spite plateau' (Spite & Spite 1982) by a factor of two or more. Several possible solutions, such as stellar destruction and astration, nuclear uncertainties and new physics, atomic diffusion etc. have been proposed to explain this discrepancy. The estimates of Li abundances in hyper metal-poor stars as well as in extreme metal-poor stars that are still in the main-sequence turn-off phases might provide a clue to this problem. High resolution and high sensitivity are required for measurements of low Li abundance and Li isotope ratios. An understanding of the Li problem and depletion processes inside stars may be achieved better by the study of metal poor globular clusters. Correlating the Li abundance with other heavy elements will help understand the discrepancy between the observed Li abundance compared to WMAP results.

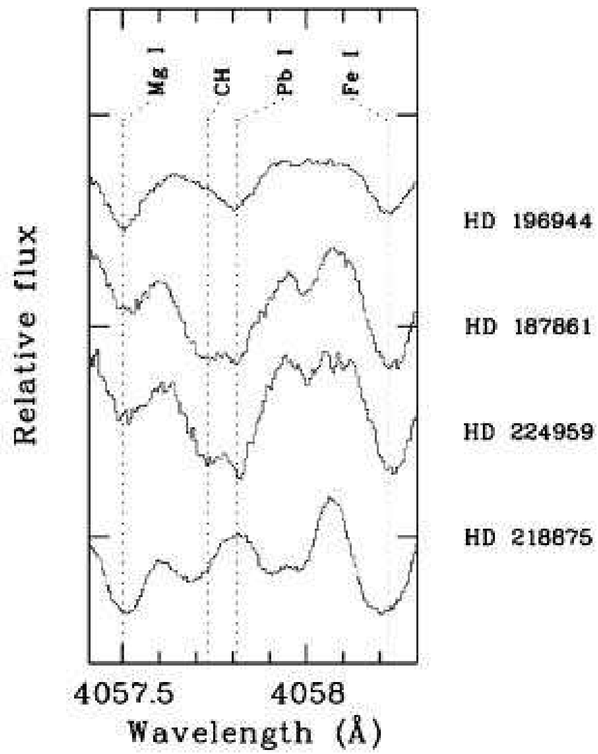

Figure 2: The presence of strong Pb I line 4057.81 Å in the three CH stars and absence in the comparison C-R star HD 218875 (R $\sim$ 135,000, and exposure times in the range 1 h 30 to 2h 30 m) (Ref: Vaneck et al. 2001, Mengr, 106, 37).

MW Bulge

Detailed studies of alpha-enhanced MW bulge stars are expected to reveal burst of star formation history. Differences between the solar vicinity disk chemistry and bulge stars becomes noticeable at metallicities [Fe/H] > 0 (Bensby et al. 2013). At such metallicities spectra suffer severe line blending; thus requiring high resolution ($>$ 90K desired) to measure separated lines for abundance calculation.

Characterization of transiting systems

Prior to the launch of the Kepler telescope in 2009, radial velocity surveys were the dominant method for discovering new exoplanetary systems with over 400 systems discovered between 1995 and 2009 (http://exoplanet.edu). After these initial discoveries, optical RV surveys progressed from measurement precisions of 10 m/s to 1 m/s due to improvements in instrument stability and data analysis methods.

In recent years, a major focus has been on RV observations for characterization of transiting systems, particularly those discovered by the Kepler mission; the combination of RV and transit is believed to be exceptionally powerful, allowing measurements of planetary densities.

The level of RV precision (1 - 2 m/s) needed for studying the planets' physical properties, key physical trends, correlation between planet occurrence and stellar metallicity etc. can be accomplished with instruments having capabilities to aid spectral stabilization, very high spectral resolution (R $>$ 90 K) and very high signal-to-noise ratios.

3. Key astrophysical observables
The strength of atomic lines and molecular bands
Measurement of isotopic ratios
Radial velocity
The redshift of the spectrum
The variation with time of the total flux in a given wavelength interval
Atmospheric parameters: effective temperature, logg, micro-turbulence, and metallicity ([Fe/H]), [α/H], [hs/Fe] and [ls/Fe] (hs: heavy s-elements, ls:light s-process elements).

The accuracy of these measurement should be at a level of < 0.1 dex
RV precision ~ 1 m/s.
The standard or envisioned technique for extracting the information from the data is using spectrum synthesis calculation using model atmospheres. The successful measurement will crucially depend on the
i) high resolution of the spectra combined with high signal-to-noise ratio.
ii) stable wavelength calibration
iii) wide span of wavelength coverage (to be able to measure lines due to heavy elements in the blue and C, N, O abundances from near IR)
iv) Multi-epoch observation for monitoring radial velocity variability and binary status.

4. Target selection
Galactic disk, halo dwarfs and bulge stars, Globular cluster stars
metal-poor stars (carbon-enhanced, carbon-normal), high-velocity objects, stars belonging to different spectral class and evolutionary stages, RGB, AGB, Post-AGBs, peculiar stars, variable stars etc. Total number of science targets required to be observed to enable science goal : $\sim$ 200 stars

5. Cadence and temporal characteristics In certain cases repeat observations may be required for understanding the binary status.

6. Calibration Requirements
i) Wavelength calibration : **Yes**
ii) Sky subtraction : **Yes**
iii) Flux (spectrophotometric) calibration : **case specific**
iv) Telluric absorption model accuracy : **Yes**

7. Data processing
i) Bias subtraction, sky subtraction, telluric absorption model, wavelength calibration
ii) spectra normalization, line identification, determination of radial velocity, examination of binary status
iii) Equivalent width measurements, generation of atomic line list
iv) Elemental abundance determination, abundance ratios.