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EVOLUTION AND FORMATION OF GALAXIES WITH THE MAUNAKEA SPECTROSCOPIC EXPLORER FACILITY

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Abstract. The Maunakea Spectroscopic Explorer (MSE) is a proposed major modernisation of the 3.6-m Canada-France-Hawaii Telescope into a 11.25-m aperture, 1.52 square degree field of view telescope. MSE is a fully dedicated facility to carry out multi-object spectroscopy surveys. MSE will provide a spectral resolution performance of $R \sim 2\,500 - 40\,000$ across the wavelength range of $0.36 - 1.8$ μm. The overall MSE project is presented in these SF2A2019 proceedings by N. Flagey (see also `http://www.cfht.hawaii.edu/`), here I outline the context and the challenges of MSE with respect to evolution and formation of galaxy populations.

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1 Context

In the ΛCDM cosmological model, the baryonic content of galaxies represents less than one percent of the observable Universe, the remaining being hydrogen gas. Even though galaxies represent little of the content of the Universe, surveying them has always brought discoveries and deeper understanding towards their formation and evolution throughout cosmic epochs. Indeed they are the site of of formation of billions of stars that make them visible through several Gyrs, they are the visible blocks emerging from the dark matter halos, and they are the result of the physical processes at work of the mass-energy content of the Universe. Galaxies from baryonic gas condensed in halos, evolve in and within the dark matter halo host. The difficulty to decipher the galaxy evolution starts as soon as baryons are considered in the dark matter halo potential well, as physical processes in action are extremely complex and highly non-linear with respect to virialised properties. Under gravity, gathering and mergers of galaxies is the mean to increase their mass and design the cosmic web. The intergalactic gas connects halos, pervades structures at large scales, gives a natural reservoir of baryons to increase the stellar mass of galaxies. To reproduce today's galaxy properties one need to understand the consequences of feedback processes (stellar, AGN) on the galaxy evolution that affect the interstellar and circum-galactic media. 3D spectroscopy with the instrument MUSE/ESO-VLT (e.g., Bacon et al. 2010; Wisotzki et al. 2016) recently opened a new parameter window to study in detail the baryon circle processes in distant galaxies. These physical mechanisms predict fundamental properties of galaxies like size, angular momentum, luminosity function. To unveil and quantify the evolution of galaxy populations one need a statistical approach using wide-field facilities. Detailed studies of stellar population (ages, kinematics, chemical abundances) enable to describe a galaxy and can help to determine backward the evolution. Nevertheless it is limited by the fact that galaxies experience stochastic growth rates (merger, accretion of sub-systems, etc.) with a continuous exchange of matter end energy between in and out. Normal galaxies undergo larger star formation in the past, but if we extrapolate the mean star formation rate of our Galaxy (1 solar mass/year) for instance, we cannot explain all stars accumulated today. Thus deep surveys of galaxies is a powerful mean to trace a coherent history of galaxy population assembly; the state-of-art and difficulty is to deduce evolution over several Gyrs. At a given cosmic epoch there is a given balance between bright (exponential) and faint (power law) galaxy population volume densities versus their luminosity or stellar mass. To relate theory and observations of luminosity and stellar mass functions (see, e.g., Benson et al. 2003; Silk & Mamon 2012; Behroozi et al.

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2013), one need representative samples in mass, in environment, and in type for instance, at any cosmic epoch and the precise distance of sources, i.e. spectroscopic redshifts. Nowadays massive redshift surveys sample representative volumes of the Universe to compare similar populations at different redshifts and are one of the prime tools of observational cosmology. Since the advent of multi-object spectroscopy (MOS) in the mid 90's, in particular with the nearby $z < 0.3$ 2dFGRS (Colless et al. 2001) and $z < 1.3$ CFRS (Lilly et al. 1995) surveys, spectroscopic surveys became routine using the wedding cake observational strategy with new wide-field MOS instruments, i.e., VIMOS/ESO-VLT (Le Fèvre et al. 2003), DEIMOS/Keck (Faber et al. 2003): *Wide* towards large scale structure, baryonic acoustic oscillation, and cluster studies, and cosmology probes, *Deep* towards the demographic knowledge of the sources and their environment, and *UltraDeep* towards the early Universe. Through last decades, surveys involve more and more massive data analysis on an unprecedented scale, calling for new and sophisticated approaches both for combining, analysing and archiving multi-parameter data (various wavelength ranges, spectral resolutions, point spread functions, target selections, etc.) in a meaningful and long-lasting manner (see, e.g., comments on the use of statistics (Leek et al. 2017)), and for organising large international collaborations. It represents a real challenge for future Astronomy.

2 Status and challenges in galaxy population evolution

A very robust and stable picture of the cosmic Star Formation Rate (SFR) density history is set (see, e.g., Madau & Dickinson (2014) and references therein) for a comprehensive compilation of the SFR history and mass assembly from $z = 0$ to $z \simeq 8$ using the literature spectroscopic surveys. In less than 4 Gyrs from $z = 8$ (end of reionisation epoch) down to $z \simeq 2$ (cosmic noon), the Universe reached its maximum star formation activity and half of the observed local stellar mass content is assembled. At $z > 8$ the observed accelerated evolution of the SFR density evolution (see, e.g., Oesch et al. 2018) requires further data to be confirmed. At $z > 2$ the specific SFR evolves proportionally to $(1+z)^{1.1\pm0.2}$ (Davidzon et al. 2017), illustrating a very efficient gas cooling in dark matter halos. All culminate at $z = 2$ (the cosmic noon in the so-called redshift desert): the cosmic SFR, the AGN activity, the galaxy growth mass, the massive black hole accretion history, the mass assembly, the morphological differentiation, the dust attenuation, etc. Thus, future MOS require the blue and NIR capabilities to span the redshift desert to understand this critical epoch. Galaxies above a certain mass must stop forming stars thanks to efficient quenching processes. Several scenarios are proposed that require to be corroborated with observations (i.e., e.g., Cowie et al. 1996; Faber et al. 2007; Ilbert et al. 2013). In particular, to probe the environment quenching, high spatial density sampling of targets is necessary, galaxy evolution being governed just as much on small scales as on large cosmological scales, and to prove the mass quenching (AGN, supernova, stellar feedbacks) large samples are required because of the stochasticity of the phenomena. Understanding galaxy formation is one of the most pressing issue in observational cosmology, with unsolved questions yet, like what drives the transformation from star forming to passive galaxies? at which scales environmental processes dominate galaxy properties? is there any co-evolution between massive black holes and galaxy properties, etc.

3 Multi-object spectroscopy facilities and MSE deep surveys

There are several anticipated wide-field MOS facilities brought together with imaging survey synergies. The 4-m class telescopes are dedicated MOS VIS facilities, like, e.g., WEAVE/WHT, 4MOST/ESO-VISTA, DESI/Mayall with field aperture larger than 2 deg. diameter to systematically probe large volumes at $z < 1$. The 8-m class ones are not dedicated facilities, like, e.g., MOONS/ESO-VLT and PFS/Subaru, but extend from the VIS to the NIR. The space dedicated facilities are NIR MOS, but slitless for Euclid and WFIRST-AFTA . In this context, we need further wide-field MOS facilities as described in the ESO report (Ellis et al. 2017) about the future of multi-object spectroscopy, especially for understanding the galaxy assembly and the cosmic web. That is one needs to resolve emission line doublets with sufficient signal-to-noise to measure internal stellar velocity dispersion that encode physical information, to observe enough volume at high redshift to probe the cosmic web and simultaneously encompass rare or extreme populations, to enable high spatial density to study close environment around galaxies and clustering measurements on small scales for modelling galaxy-halo properties, to optimise surveys for the physics of galaxy formation on a statistical basis and not only for cosmological studies. On the cosmological side, Colless (2019) presents key questions that will remain in 2030 that will not be refined versions of those answered by future cosmological surveys in 2020 (e.g., observation of the variation of fundamental constants, direct measure of the expansion rate, observation of non general relativity behaviour).

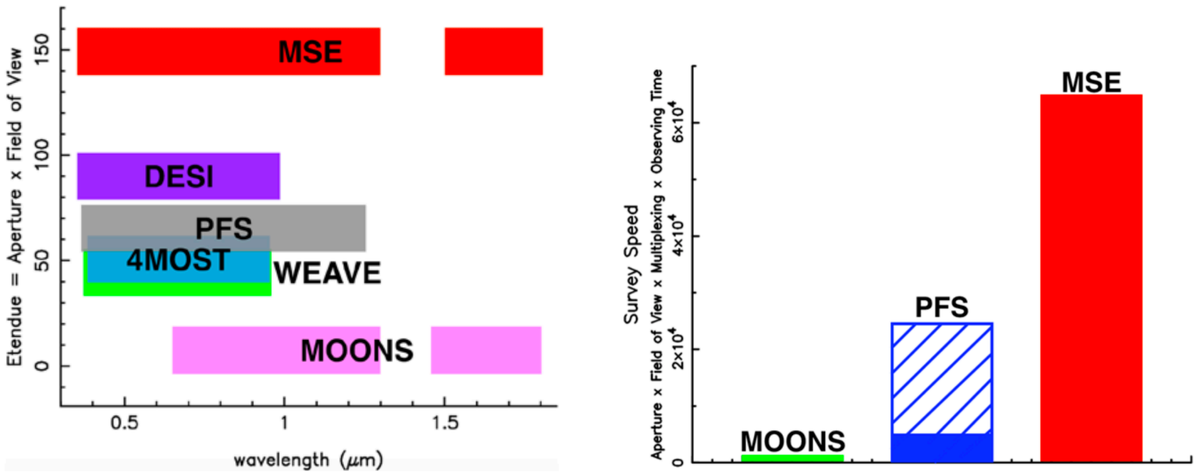

Fig. 1. Left: Etendue factor (=Aperture x Field of View) as a function of wavelength, and **Right:** Comparison of the survey speeds (Aperture x Field of View x Observing time) of the 8-10 m class anticipated wide-field MOS capabilities, published in Hill et al. (2018).

I refer also in these SF2A2019 proceedings to C. Yèche contribution, or Percival et al. (2019). MSE will enable studies which are not possible with anticipated wide-field MOS facilities, it will be the largest of these facilities and the only dedicated facility on a large aperture telescope that could be operational in 2030. MSE is designed to enable efficient massive spectroscopy surveys and to remain productive for several decades, it will surpass its original rationale as proved with most astronomical facilities. As shown in Fig. 1 its entendue ($= \mathrm{FOV}\pi(M1/2)^2$) will be a factor 20 and 2 and its survey speed (= etendue x multiplexing x observing time) a factor 6 and 3 with respect to MOONS and PFS facilities. With its R=3000 resolution mode in VIS and NIR, MSE will enable

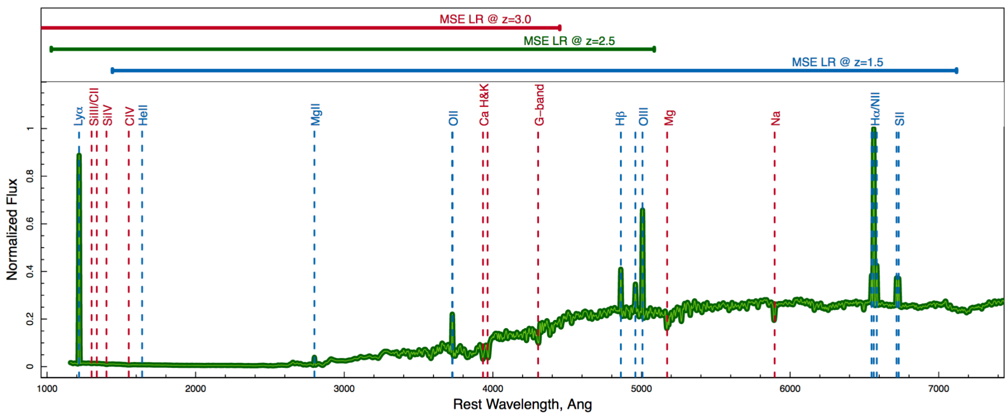

Fig. 2. A typical galaxy spectrum showing key emission and absorption lines features.The top panel displays the MSE low/mid-resolution wavelength range at $1.5 < z < 2.5$. At $z > 1.5$, MSE will observe all key optical features; at $z \approx 2.5$, it simultaneously links Lyman-and UV-absorption lines with optical emission lines; MSE retains the ability to observe [OII] and Ca H&K features to $z \approx 3$, published in The MSE Science Team et al. (2019).

the acquisition of statistical galaxy surveys at the cosmic noon epoch ($1.5 < z < 3$) in observing all key optical features at $z = 1.5$, in simultaneously linking Lyman-α and UV absorption lines with optical emission lines at $z \simeq 2.5$ and in observing [OII]$\lambda\lambda$3726,3729 and Ca H&K features to $z \simeq 3$ (see Fig. 2). MSE deep surveys over 20 - 80 sq. deg. areas will cover ranges of environment explored by local surveys with similar stellar masses, completeness and cosmological volumes. The MSE Science Team et al. (2019) present several possible surveys, for instance a 20 sq. deg. survey designed to explore galaxies and their environments at $1.5 < z < 3$ with 90% completeness at $i = 25.3$ mag using 3 million fibre hours. One major goal is to link galaxies to the large scale structure of the Universe through the peak of star formation and galaxy assembly to trace the transition from merger-dominated spheroid formation to the growth of discs, and thus to span spatial scales encompassing non-linear regime from Kpc to Mpc. Such a SDSS-like survey (`https://www.sdss.org/`) at $z \simeq 1.5$ represent a 5-7 yr programme only possible with a dedicated facility like MSE.

4 Conclusion

As a powerful, efficient and reliable survey machine, MSE will unveil fundamental quenching processes in the galaxy population on statistical basis, and will be complementary to anticipated MOS surveys or much smaller FOV instrumentation. Updates on the project are given at `http://www.cfht.hawaii.edu/`).

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