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L. Cambrésy, F. Martins, E. Nuss and A. Palacios (eds)

THE ELT-MOS WHITE PAPER.

M. Puech[1] and the MOSAIC consortium

Abstract. Several prominent E-ELT science cases will require at least one Multi-Object Spectrograph (MOS). The science cases for an ELT-MOS were revisited and summarized into an ELT-MOS White Paper, which is available on astro-ph. We briefly present its content and discuss two specific requirements on the sky subtraction accuracy with fibers and the optimal IFU pixel scale for galaxy evolution and formation studies.

Keywords: Extremely Large telescopes, multi-object spectroscopy, distant galaxies, sky subtraction, integral field spectroscopy.

1 Introduction: MOSAIC, a new MOS concept for the E-ELT

Multi-object spectrographs are currently the workhorse instruments of the 8-10 meter class observatories. These facilities are indeed very efficient in providing extensive spectroscopic follow-up observations to both ground-based and space-borne imaging surveys. During the E-ELT instrument phase A studies in 2008-2010, several instrument concepts were studied including three MOS concepts, namely EAGLE (Cuby et al. 2010) an near infrared multi-integral field spectrograph fed by multi-object adaptive optics (MOAO), OPTIMOS-EVE, an optical-near infrared MOS (with IFUs or mono-aperture fibers; Navarro et al. 2010), and OPTIMOS-DIORAMAS, an multi-fiber optical-near infrared MOS (Le Fèvre et al. 2010). ESO subsequently announced that the two first light instruments will be a near-infrared camera (ELT-CAM) and a near-infrared mono-object integral field spectrograph (ELT-IFU). The MOS remains in competition for the third slot of the E-ELT instrument road-map.

Since then, as series of meeting were organized to re-examine the scientific needs for a MOS on the E-ELT and find synergies between the different MOS concepts studied in phase A. Two of the three phase A MOS consortia decided to join their efforts into the new MOSAIC international consortium (see Hammer et al., these proceedings). The goal of MOSAIC is to provide the best of the two EAGLE and OPTIMOS-EVE concepts at lower cost and complexity.

2 The ELT-MOS White Paper

As a first step, it was decided the revisit the science cases for an ELT-MOS. This process was stimulated by several international and national meetings held in Amsterdam (in Oct. 2012) and in several European countries (i.e., UK, Italy, Brazil and Netherlands). The conclusions of these meetings were summarized in a White Paper, which is now available on astro-ph (Evans et al. 2012).

We identified the six following prominent science cases for the ELT-MOS:

- SC1: First light and spectroscopy of the most distant galaxies;
- SC2: Spatially-resolved spectroscopy of high-z galaxies;
- SC3: Role of high-z dwarf galaxies in galaxy evolution;
- SC4: Tomography of the IGM;

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[1] GEPI, Observatoire de Paris, CNRS-UMR8111, Univ. Paris-Diderot, 5 place Janssen, 92190 Meudon, France

- SC5: Resolved stellar populations beyond the Local Group;
- SC6: Galaxy archaeology with metal-poor stars.

Some of these science cases were detailed using end-to-end simulated observations. Our goal is to update the White Paper regularly with additional inputs from the community and to progressively fill each key science case with such simulations. During the E-ELT instrument phase A studies, we developed a very versatile simulation tool called WEBSIM*. This tool was extensively used to validate the science top level requirements of EAGLE (Evans et al. 2010) and OPTIMOS-EVE (Navarro et al. 2010), as well as during the E-ELT Design Reference Mission (Puech et al. 2010b). It consists in a web interface coupled to an IDL code, which allows the user to conduct full simulations in several observing modes (i.e., mono-aperture fibers, seeing or AO-assisted IFUs) with realistic PSFs. Details about WEBSIM can be found in Puech et al. (2010c).

Investigating these science cases led us to define a Top Level Requirement (TLR) matrix, which list the required spectral and spatial resolution, multiplex, FoV, and spectral bandwidth for each of them. The next step is to prioritize the TLRs and iterate with technical and operational feasibility. The end-to-end simulations are decisive tools to assist in the required trade-offs between these requirements (e.g., spectral bandwidth vs. multiplex vs. spatial resolution; see Disseau et al., these proceedings). The MOSAIC TLRs, as derived from the ELT-MOS White Paper, led us to define two main observing modes, i.e., the High Multiplex Mode (HMM) *à la* OPTIMOS-EVE, with ∼100-250 mono-aperture fibers with GLAO/seeing resolutions, and a High Definition Mode *à la* EAGLE, with ∼10 MOAO-fed IFUs with 40-80 mas sampling. The HMM mode is dedicated to the study of the integrated light emitted by the most compact sources of interest (e.g., very first galaxies, dwarf satellite galaxies), while the HDM is necessary to spatially-resolve the properties of, e.g., distant galaxies, with large enough signal-to-noise ratios. These two modes have been implemented into two preliminary concepts, which are now under evaluation by the consortium against the MOSAIC scientific TLRs (see Hammer et al., these proceedings).

3 SC1: first galaxies and reionisation

This science case is one of the prominent science cases of the E-ELT. The goal is to investigate the sources responsible for the reionisation of the Universe at very high redshift, i.e., between $z\sim7$-20. This is intimately linked to the search of the very first galaxies, which are expected to be very small (i.e., $R_{half}\sim$100-200 mas) and faint (i.e., J_{AB}=27-30) objects (see, e.g., Grazian et al. 2012). One of the key requirement (see Evans et al. 2012) is to detect galaxies down to J/H_{AB}=27-28 in absorption (using the UV interstellar lines or the Lyman break), and $J/H_{AB}\sim30$ in emission (using the Ly-α line).

Detecting sources in absorption down to J/H_{AB}=27-28 is very challenging because of the relatively high sky continuum background in the near-infrared, which is typically as bright as J/H_{AB}=19.5-20 between OH lines (e.g., Sullivan & Simcoe 2012). This translates into the requirement that the sky continuum subtraction must be as accurate as 0.1%, otherwise systematic residuals will prevent detecting J/H_{AB}=27-28 sources. It has long been argued that optical fibers cannot reach such a level of accuracy. To address this issue, we tested a cross beam switching observing mode using technical time on sky with FLAMES-GIRAFFE in MEDUSA mode (i.e., the multi-fiber mode of GIRAFFE). This observing mode consists in using the fibers in pairs with constant distance (here 12 arcsec), one pointing at the target, while the second one samples the sky background. Both fibers are sampling the object and sky alternatively using an ABBA sequence (see Fig. 1). This was found to be very efficient in removing the differential fiber response. The residual systematic effect is found to be only 0.6±0.2% of the sky continuum background (Yang et al. 2013), which corresponds to the physical limit associated to the spatial variations of the sky continuum (Puech et al. 2012; Yang et al. 2012). In other words, provided that cross beam switching observations are used, fiber can reach the same accuracy that slits. The remaining limiting effect is found to be scattered light in the instrument. Specific algorithms and purposely-designed instruments should be able to reach an even better accuracy, probably as small as ∼0.1% (Sharp & Parkinson 2010). Even better performances should be reached with the IFUs, since the sky continuum is sampled continuously around the target. Such an observing mode has been adopted as a baseline for MOONS, a third generation MOS for the VLT (Cirasuolo et al. 2012).

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[*] visit https://websim.obspm.fr

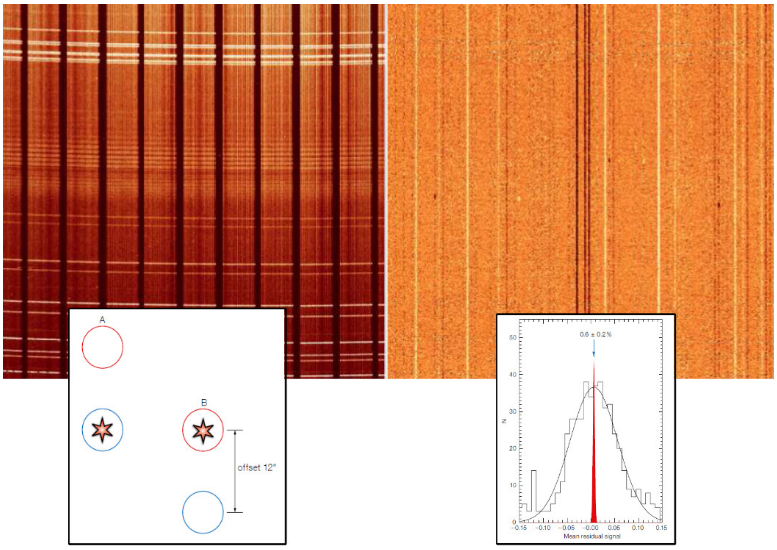

Fig. 1. On-sky demonstration of the cross beam switching observing mode with FLAMES-GIRAFFE fibers. The bottom left panel illustrates the observing operations: the target in observed in a given fiber while the nearby sky signal is measured by another fiber (seq. A); then the telescope is offset by the distance between the two fibers to switch the object and sky w.r.t. the two fibers (seq. B). The upper left panel shows the raw spectra obtained in the GIRAFFE fibers after observing blank regions (i.e., the sky background signal). Wavelength increases along the vertical axis, while columns are different fibers spread over the field of view. The left panel shows the result of the ABBA sequence after subtraction on the raw data. The bottom right panels show the distribution of the residual on the sky continuum background signal after subtraction on the fully reduced data after a detailed analysis (Yang et al. 2013).

4 SC2: spatially-resolved spectroscopy of galaxies

The goal of this science cases is to better understand how galaxies formed and evolved. When observing distant galaxies (i.e., at $z \geq 1$), a significant fraction of them reveal relatively thick disks with a clumpy light distribution (e.g., Elmegreen et al. 2007; Puech 2010). Such clumps are thought to be potentially important in galaxy evolution (e.g., Bournaud et al. 2013). Better understanding the relation between these clumps and the underlying disk requires to spatially-resolve the clumps internal kinematics.

Specifying the spatial sampling of an IFU requires determining the optimal trade-off between spatial resolution and sensitivity (Puech et al. 2008). This generally translates into choosing the largest spatial scale which allows one to spatially-resolve the structure of interest, hence providing the best signal-to-noise ratio for resolving it. During the EAGLE Phase A study, this led us to adopt an IFU pixel scale of 37.5 mas to resolve distant clumps. However, it is now known that ELT-IFU will provide from first light exquisite diffraction-limited spatially-resolved observations of distant galaxies. In addition, a lot of efforts are currently underway at the VLT with SINFONI+AO (assisted by the Laser Guide Star, see Newman et al. 2013). It is therefore very likely that samples of tens or perhaps hundreds of clumpy galaxies with high enough spatial resolution will be assembled by the time ELT-MOS will become available. Instead of optimizing the MOSAIC IFU spatial resolution for resolving clumps (as was the EAGLE IFU during Phase A, see Puech et al. 2010a), an alternative would be to optimize the IFU pixel scale for resolving the overall size of distant galaxies, on which the dynamical state is imprinted. This allows distinguishing an ongoing merger from a relaxed rotating disk (Puech et al. 2008, 2010b). Simulations then reveal that this should be possible up to $z \sim 4$ and down to sub-M^* (or up to $z \sim 5.6$ and down to only M^* galaxies) with a spatial sampling of only 50-75 mas (see Fig. 2)). Optimizing the ELT-MOS IFU that way in survey speed would be an interesting niche for MOSAIC, which would then be able to observe hundreds of distant galaxies in a limited amount of nights.

5 Conclusions

A MOS on the E-ELT will be essential to achieve a number of prominent science cases. We revisited the ELT-MOS science cases in a White Paper, which is available on astro-ph. New versions with additional inputs

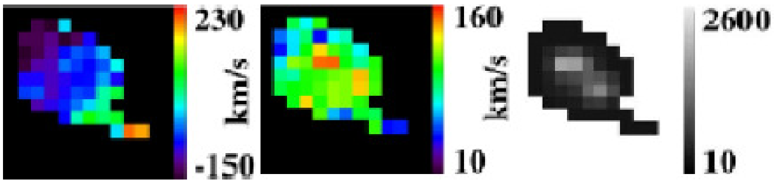

Fig. 2. Kinematics of a major merger as derived from simulations of IFU observations at z4, with 75mas/pixel, integratino time of 24h and MOAO correction with EE=34%. The velocity fields (first column), the velocity dispersion maps (second column), and the emission line flux maps (last column, units are in median counts per dit) are shown. The object size is 0.8 arcsec in diameter, which represents 0.12 kpc at z=4. The two progenitors can be cleary seen in the emission line map. See Puech et al. (2008) for details.

from the community and further observation simulations will be issued regularly. These scientific inputs led us to define MOSAIC, a new conceptual study for an ELT-MOS that builds on the previous EAGLE and OPTIMOS-EVE phase A studies. Simulations of the different ELT-MOS science cases are on-going. If one wants to optimize the MOSAIC IFU pixel scale for survey speed (i.e., in terms of signal-to-noise ratio), the simulations conducted so far suggest an optimal pixel scale close to 80 mas.

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