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MOSAIC FOR THE ESO ELT: THE FRENCH PERSPECTIVE

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Abstract. MOSAIC at the ELT will be the most powerful facility to observe a large number of faint sources that are unreachable by other optical facilities, and its exploitation will lead to a gigantic step into the deep Universe. It will also become the largest ground-based instrument and Consortium ever implemented in the astronomy and astrophysics domain. The French community is leading the MOSAIC effort, which will be rewarded by a strong leadership in many astrophysical fields, including by operating surveys for an equivalent amount of more than 50 nights on the largest world class telescope of the 2020s.

Keywords: Multi-object spectrograph, ELT, cosmology, galaxies, dark and baryonic matter, Local Universe, Local Group, the Galaxy, stars

1 Introduction

The ELT will be the world largest visible/NIR telescope in the 2020s, with a collecting area similar to the total of the 16 currently existing 8-10 meter class telescopes. When combined with the huge collecting area of the ELT, MOSAIC (*http://www.mosaic-elt.eu/*) will be the most effective and flexible Multi-Object Spectrograph (MOS) facility in the world, having both a high multiplex and a multi-Integral Field Unit (Multi-IFU) capability. It will be the fastest way to spectroscopically follow-up the faintest sources, probing the reionisation epoch, as well as evaluating the evolution of the dwarf mass function over most of the age of the Universe (Evans et al. 2016; Hammer et al. 2016; Morris et al. 2018a). MOSAIC will be world-leading in generating an inventory of both the dark matter (from realistic rotation curves with adaptive optics fed NIR IFUs) and the cool to warm-hot gas phases in $z=3.5$ galactic haloes. Galactic archaeology and the first massive black holes are additional targets for which MOSAIC will also be revolutionary. MOAO (Morris et al. 2018b) and accurate sky subtraction with fibres (Yang et al. 2013) have now been demonstrated on sky, removing all low Technical Readiness Level (TRL) items from the instrument. A prompt implementation of MOSAIC is feasible, and indeed could increase the robustness and reduce risk on the ELT, since it does not require diffraction limited adaptive optics performance.

Science programmes and survey strategies are currently being investigated by the Consortium together with ESO. Given the paradigm proposed by ESO for financing the hardware cost of the instrument, we are hoping to welcome a few new partners in the next few years, in particular those interested in financially supporting the project in exchange of Guaranteed Observing Time. The Phase A Consortium includes countries in the core of the project (Partners: France, United Kingdom, The Netherlands, Brazil, Germany) as well as other participating countries (Associate Partners: Austria, Finland, Italy, Portugal, Spain, Sweden). Since that time, the University of Michigan has joined the project, and discussions are in course with other partners (e.g., STSci).

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We are actively preparing the final top level requirements for the instrument as well as the management of the Consortium, which is expected to gather about 15 Countries or main Institutes, and up to 40 laboratories. In particular the Project Office is implemented in France under the Principal Investigator responsibility, and it will supply for many activities on behalf of the Lead Technical Institute hosted at CNRS.

2 Science

During the Phase A study, the MOSAIC Consortium gathered with the science community at large in four key international meetings (Cefalu, September 2015; Paris, March 2016; Toledo, October 2017, Heidelberg, March 2019), and prioritized the numerous science cases developed over the years for MOSAIC, and which are expected to open many new astronomical avenues in the coming decade. These discussions identified four key science cases which have been used to help with instrument tradeoffs (HDM: High Definition Mode; HMM: High Multiplex Mode):

1. First-light galaxies: only a MOS at the ELT is able to catch the population at z=6 to 15, which is very rare and need a significant multiplex (HMM-NIR) for disentangling them from the huge population of foreground objects. With the HDM that allows an accurate sky-subtraction, MOSAIC will be unique for catching the faintest galaxies (e.g., the most distant) and to identify the origin of the ionizing photons possibly responsible for the reionisation of the universe up to one or two magnitudes deeper than what JWST will provide (Vanzella et al. 2014).

2. Evolution of dwarf galaxies that is the largest galaxy population in number, which is also candidate for being responsible of the reionisation. MOSAIC will provide comprehensive studies of their chemistry, stellar population and also of their kinematics up to depth, distances, and spectral resolution unreachable by any other means including JWST (main modes: HDM & HMM-NIR)

3. Inventory of baryonic and dark matter in the distant Universe, up to z=4. The numerous rest-frame UV lines are probing the cold to warm and warm-hot gas in galactic haloes allowing to estimate their baryonic content (Werk et al. 2014). MOSAIC will be able to observe in the visible range (HMM-VIS) their redshifted counterparts (Japelj et al. 2019) at z=3-4 thanks to the gigantic ELT aperture. Using multi-IFUs in the near-IR (HDM) will allow to study the rotation curves of many high-z galaxies allowing to sample the dark matter in the distant Universe.

4. Extragalactic stellar populations: only MOSAIC will be able to study very distant red super-giant stars up to 30 Mpc allowing to directly study the chemistry of all types of galaxies, as well as to distinguish the main sequence star population in the Local Group to determine the distance of galaxies even those containing less than a thousand stars (main modes: HDM & HMM-NIR).

Many of the above science cases have ben simulated (Puech et al. 2018). It results that the main goals of MOSAIC are unreachable by any other means, and that it is very complementary with, e.g., JWST and HARMONI.

3 Top level requirements and design

The top level requirements have been refined since the end of the Phase A in March 2018, also in order to reduce the number of modes and then the instrument complexity and cost, as well as keeping sufficiently large multiplex. In particular it has led us to keep the HMM in both visible and Near-IR with a multiplex ranging from 100 to 200. The HDM multi-IFUs are kept only in the Near-IR and are intended to provide the best sky-subtraction for detecting ultra faint sources, and also to derive distant galaxy kinematics. The instrument concept is summarized in Fig. 1 and will include not less that 4 spectrographs in Near-IR and 2 spectrographs for addressing the visible range, with the interesting feature that observations can be operated in parallel in the two wavelength ranges.

4 MOSAIC status at ESO

MOSAIC is currently in pre-Phase B under Consortium responsibility. Besides finalizing the instrument design for the construction phase, we are working at preparing the Consortium and its overall management. This

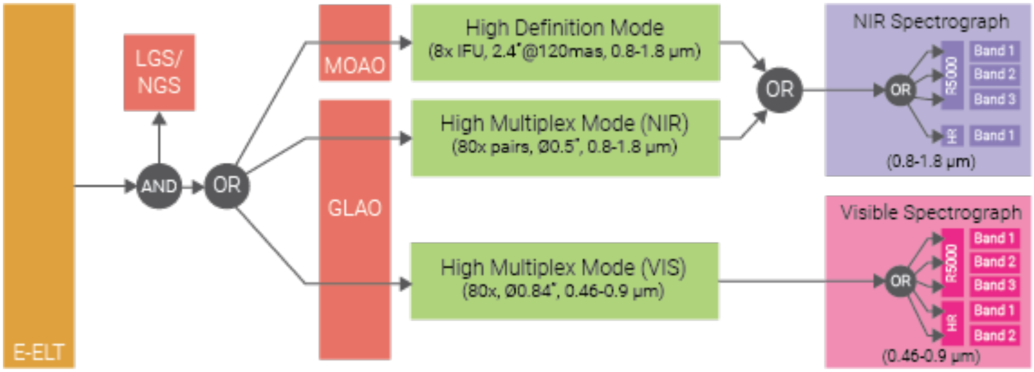

Fig. 1. The MOSAIC instrument concept. Notice that the multiplex number as well as apertures are still in discussion and are expected to be consolidated this Autumn 2019.

includes the Memorandum of Understanding between partners, which will determine their contribution in the making of the instrument as well as how they will be retributed in guaranteed time observations (GTO), which amounts to a total of not less than 125 nights. For the later, the partners gathered into the Steering Committee have already agreed for a share of common surveys, which renders more ambitious the GTO exploitation and simplifies the scientific coordination of the project.

MOSAIC (as well as HIRES) is a second generation instrument that will be on sky after the first light instruments. This situation has generated significant delays for its implementation related to the management of the telescope and of other instruments. We are grateful to ESO for the recent increase of the managerial support for preparing Phase B and its associated documentation.

5 Conclusions

MOSAIC is supported by a very large community in astronomy, and has been part of the ELT instrumentation plan for over a decade. When implemented on the largest telescope in a foreseeable future, it will be the most efficient facility to study the early Universe and its composition (baryons and dark matter) as well as many programs requiring statistics (stars or galaxies), source identifications, and environmental studies. MOSAIC is unique in studying all sources not reachable by spectrographs not implemented on the 10 meter class telescopes. For example, it will increase by a factor 125 the volume within which individual stars can be observed and analysed, and allow proper analyses of the first galaxies up to 27 (29) AB magnitudes for quiescent (emission line) galaxies, respectively (see Fig. 2).

MOSAIC is also the largest ground-based instrument ever undertaken in astronomy, both from an instrumental and a managerial viewpoints. Its weight allocation on the ELT Nasmyth Platform 2 is up to 40 tons, and its total cost could reach 80 million euros. It is the only ELT instrument with a French leadership, which implies the need for a substantial support in the community and from the French Institutes. In exchange, the French community may have a privileged access to more than a third of the scientific exploitation of the instrument, through the scientific management (preparation, implementation, observations & data analyses) of a significant part of the surveys (Evans et al. 2018) that will be accomplished during the GTO time. Since the next year should be the time for starting the Construction Phase, and because the project is expected to be on sky in the late 2020s, contributions of scientists and engineers from all French laboratories are highly welcomed. In particular, we hope that young scientists will join or will be hired by the Consortium for performing simulations in order to consolidate the instrument design, its operability, and the surveys that will lead to significant breakthroughs in most astrophysical domains. With MOSAIC the French scientific community will access to the leadership for studying the most distant objects (galaxies or stars) ever observed in the Universe.

We are very grateful and indebted to the international MOSAIC team without which making MOSAIC a reality would not be possible. We warmly thank the support of the CNRS-INSU, the Paris Observatory and the LAM, GEPI, LESIA, and IRAP laboratories for their active roles during the early phases of the MOS for the ELT.

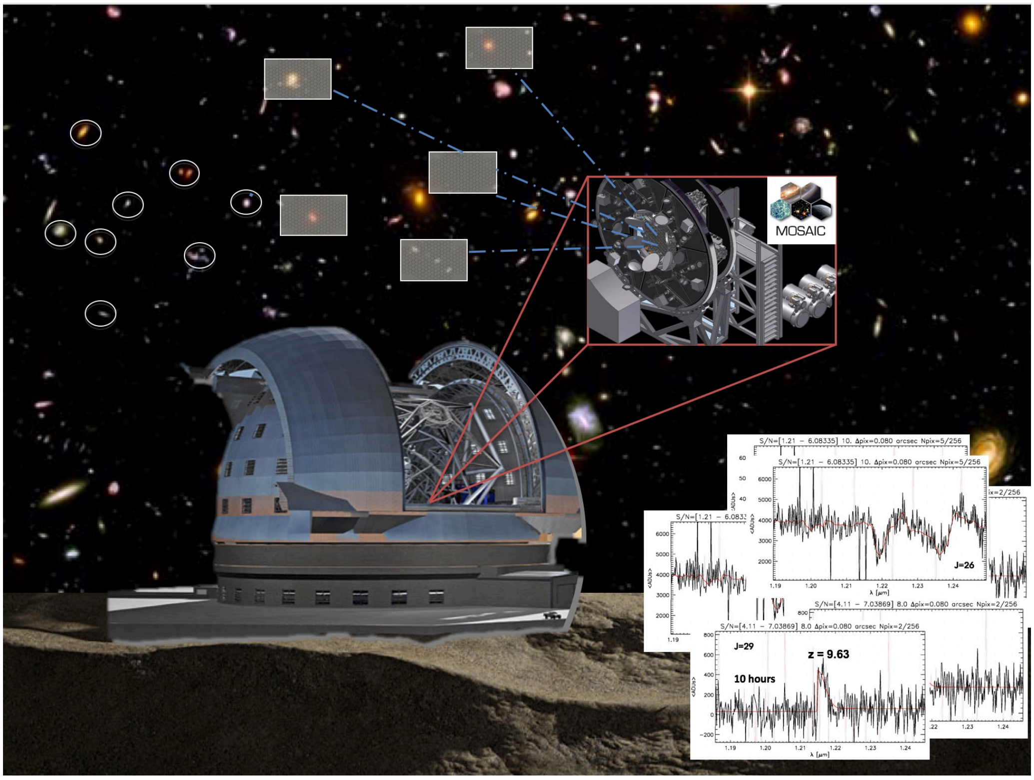

Fig. 2. A montage to illustrate how MOSAIC, when implemented on the E-ELT, will take hundreds of spectra exploiting its HDM-IFUs (rectangles) and HMM-fibres (circles), allowing the discovery and the quantitative study of the faintest and most-distant galaxies in the Universe. Spectra of AB=29 (AB=26) emission (absorption) line galaxies at very large redshifts are from simulations made by Disseau et al. 2014

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