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MOSAIC: THE ELT OPTICAL AND NEAR-INFRARED MULTI-OBJECT SPECTROGRAPH

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Abstract. MOSAIC is the future multi-object spectrograph for the ESO 39 meter Extremely Large Telescope, the ELT. We give here a brief summary of the project status, which has entered phase B1 with ESO in march 2023.

Keywords: Spectroscopy, ELT, galaxies, reionisation, inter-galactic medium, stellar populations, multi-messenger astronomy

1 MOSAIC at the ELT

The ESO's 39 meter Extremely Large Telescope (ELT) will see it first light in 2028 (see Spyromilio et al., this conference). Besides the four first light instruments (MICADO, see Clénet et al., this conference, HARMONI, see Bouché et al., this conference, MORFEO, see Douté et al. this conference, and METIS, see Pantin et al., this conference), two other instruments are planned as part of the ELT instrument roadmap, ANDES, a high-resolution spectrograph, and MOSAIC. MOSAIC [*†] is a versatile multi-object spectrograph dedicated to a large number of science cases for which multiplex capabilities are required (see e.g., Puech et al. 2018; Sánchez-Janssen et al. 2020).

MOSAIC will provide unique observational capabilities at the ELT, with multi-object observations at moderate spectral resolution. It is intended to make use of the entire Field of View available at the ELT (∼40 arcmin^2). The instrument will cover the optical and near-infrared domains with three observational modes. The requirements are the following:

- The MOS-VIS mode will provide integrated spectra of ∼200 objects at the same time, covering the ∼0.45-0.77 μm optical range with two bands. The spectra will be obtained using on-sky apertures of diameter 0.7 arcsec, with spectral resolution R>4000. Alternatively, it will possible to observe ∼70 objects at higher spectral resolution R∼18000 within two narrower windows of specific interest (see below);
- The MOS-NIR mode will provide integrated spectra of ∼200 objects at the same time, covering the ∼0.77-1.8 μm near-infrared range in a single band. The spectra will be obtained using on-sky apertures of diameter 0.6 arcsec, with spectral resolution R>4000. Alternatively, it will possible to observe ∼70 objects at higher spectral resolution R∼18000 within two narrower windows of specific interest (see below), including the CaT triplet;

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*http://www.mosaic-elt.eu/
†https://elt.eso.org/instrument/MOSAIC/

- The mIFU mode will offer Integral Field Units for parallel observations of up to 8 extended objects, covering the same wavelengths that the MOS-NIR mode. The individual Field-Of-View of each IFU will be ∼2.5 arcsec in diameter, with hexagonal shape. Each spaxel (also hexagonal) will be 150mas on-sky, providing coarser spatial resolution compared to HARMONI, but optimised to reach higher surface brightness sensitivity for faint extended objects.

All MOSAIC modes will be assisted by Ground-Layer Adaptive Optics using both Natural and Laser Guide Stars. All modes are designed to provide the best possible survey speed, i.e., to minimize the amount of observing time necessary to reach the required signal-to-noise ratio for all targets in the large statistical samples required by the different MOSAIC science cases (see below and Puech et al. 2018, for further details).

While other ELT instruments will focus on exploiting the central part of the ELT focal plane, MOSAIC will exploit a much larger area (see Fig. 1). At this scale, one has to take into account the fact that the ELT focal plane is non-telecentric. For this reason, MOSAIC is developping an original stepped and tiled focal plane design (see Fig. 1) made of 300 segmented tiles, which can be individually oriented in space to provide local telecentricity. Three distinct families of tiles are being designed, corresponding to different sets of optical fibers/pick-off mirror they will carry, each of them addressing different observing modes: 100 tiles will carry optical fiber bundles suited for MOS-VIS observations (either at low or high spectral resolution), 100 will carry optical fiber bundles suited for MOS-NIR (either at low or high spectral resolution), and 100 other tiles will carry bundles suited for either MOS-VIS or MOS-NIR observations. This design will provide MOSAIC with the very interesting capability of observing in parallel different objects within the same field-of-view with different modes, within the limit of 200 objects at the same time. This will boost the observational efficiency of the instrument.

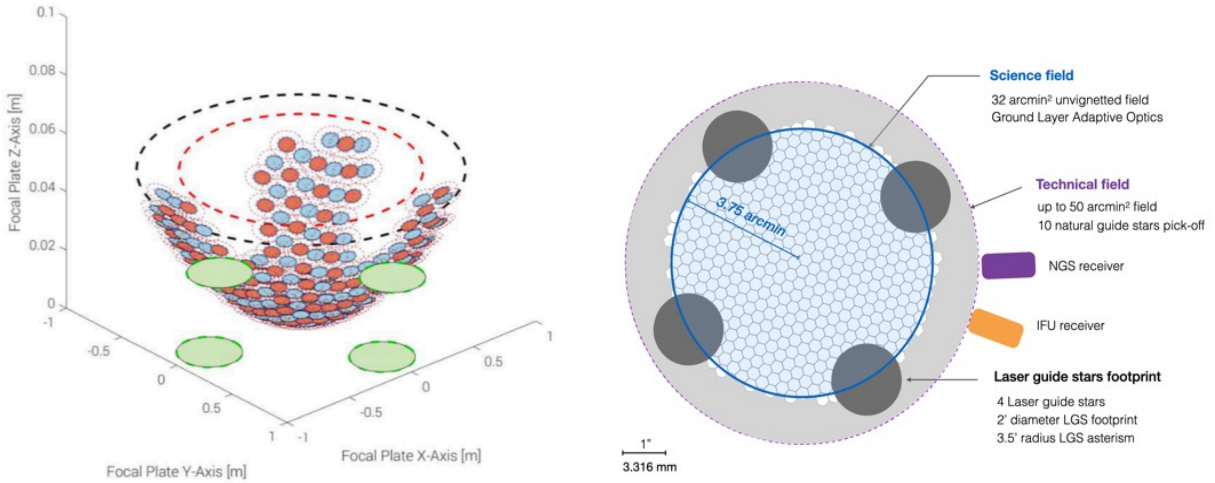

Fig. 1. Left: Illustration of the MOSAIC stepped and tiled focal plane design. The green circles represent the footprints of the 4 Laser Guide Stars, over which no scientific targets can be observed. The blue and red spots represent different families of tiles (see text), which are used to collect the light from different objects in the field-of-view and relay the light towards different observational modes. These tiles can be oriented in space so that telecentricity is locally recovered. **Right:** Top view of the MOSAIC focal plane concept. The tiles are represented by the white hexagones within the science field-of-view area. Their function is to collect the light from objects of interest and re-inject it within optical fiber bundles mounted beneath them. They can also redirect the light towards the 4 Natural Guide receivers or the 8 IFU receivers distributed on the focal plane edge, which will redirect the light towards the NIR spectrograph.

2 Status of the Project

The MOSAIC project was built on the legacy of three former E-ELT phase A instrument studies, EAGLE (Morris et al. 2012), OPTIMOS-EVE (Navarro et al. 2010), and OPTIMOS-DIORAMAS (Le Fèvre et al. 2010). MOSAIC completed its own Phase A conceptual study with ESO in 2016-17 (Morris et al. 2018). The project was largely reorganised in 2021-22 to prepare for a preliminary design phase (phase B, see Fig. 2). This important milestone was reached in march 2023. The consortium, with CNRS/INSU as lead technical

institute, signed over this summer an agreement for a Phase B1 study whose duration is 1.5 years, leading to a Specification and Architecture Review in 2024.

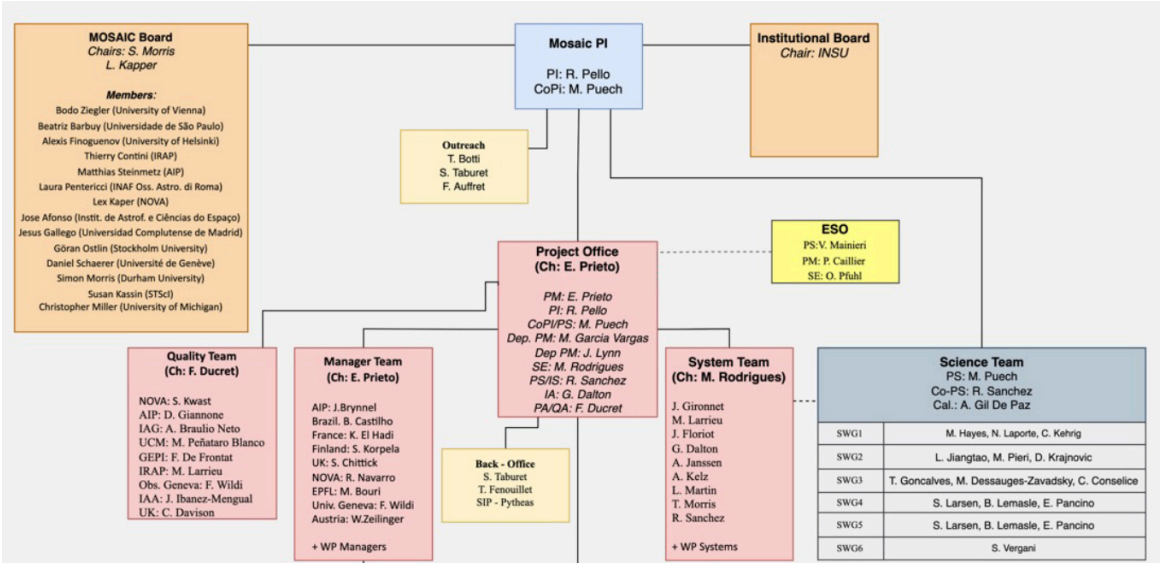

Fig. 2. Organigram of the MOSAIC project.

The particularity of MOSAIC (and ANDES), compared to other ELT instrument projects, is that ESO will not provide any hardware contribution, meaning that the consortium has to raise funding for both the human ressources and hardware procurement. The current budget is currently estimated to ∼750 ETP and 51 M€. Raising such ressources results in a quite large consortium of ∼ 350 members from 31 laboratories in 22 institutional partners spread over 14 countries. The consortium is still growing, since new partners are expected to complete the project budget in the coming years. French laboratories are leading several important Work Packages (WP) within the consortium: the NIR Spectrograph WP (LAM together with Spain), the m-IFU fiber link WP (GEPI), the optical relays WP (OCA/Lagrange), the Electronics and Instrumental Control System WP (IRAP), and the Science Software WP (LAM-GEPI).

The project is currently involved in a consolidation phase during which the partner contributions are reviewed and consolidated. The preliminary conclusions of this phase are suggesting that the MOS-VIS mode appears to be sufficiently mature to be further developped, with most of the required founds available, while the MOS-NIR and mIFU modes would require more founds to be raised (in particular for the detectors) and additional technological developments to be conducted. In this respect, several R&D actions are currently conducted or identified related to the NIR spectrograph camera, the focal plane positioner, or the possible implementation of an Atmospheric Dispersion Corrector. This might lead to a decision to develop the visible channels with a more agressive timeline (with a possible first light foreseen in ∼2031) compared to the NIR channels (∼2032).

The projects is currently also reviewing several design trade-offs:

- wavelength coverage in MOS-VIS: an extension towards the blue is studied with the goal of reaching 0.39μm. Several absorption lines of interest are indeed expected at these wavelength, which are important for the chemical characterization of stars. Other science cases would also benefit a lot of such an extension (e.g., tomography of the IGM, mass assembly). This extension is limited in efficiency by the current throughput of the ELT coating, which is optimised for near-infrared wavelengths;

- use (or not) of an ADC: several technical possibilites are currently studied (global ADC or individual ADC implemented within each individual optical path). Implementing an ADC increases the cost of the instrument but might lead to a simple opto-mecanical design of the optical relays and facilitates a reduction of the number of observing bands in the VIS.

These trade-offs should be finalised by the end of 2023.

3 MOSAIC surveys

All MOSAIC partners already agreed to pool the Guaranteed Time Observations (GTO) granted by ESO as a reward for building the instrument and share it to conduct ambitious and transformative surveys. Presently, the expected GTO consists on 65 nights for the FTE contribution, plus an additional reward for the hardware contribution, which remains to be negociated with ESO in the subsequent phases.

The large Science Team is reorganised into six Science Working Groups corresponding to the prominent MOSAIC science cases (see e.g. Puech et al. 2018; Sánchez-Janssen et al. 2020):

- First light galaxies and reionisation; In particular, MOSAIC will measure UV rest-frame spectra of the most distant galaxies, which is essential to assess their role in the reionisation of the Universe;
- Inventory of matter: MOSAIC will provide the first exhaustive census of matter at z∼3, combining measurements of the tomography of cold gas in the inter-galactic medium, of the abundances of metals in the haloes of galaxies, and of the dark matter content of z∼3-4 galaxies;
- Mass assembly of galaxies through cosmic time, focusing in particular on the spatially-resolved kinematics of low-mass galaxies out to z∼4 and on the stellar dynamics of massive galaxies at high redshifts;
- Stellar populations in and beyond the Milky Way, to unveil the past star formation and evolution history of galaxies, or probe low-metallicity stars in a variety of environnements;
- Transients and multi-messengers, to assess the possible role of MOSAIC in the identification and characterization of their electromagnetic counterparts.

The MOSAIC Science Team, which encompasses more than 290 colleagues from 14 countries, has started the long process of building the future MOSAIC surveys. This process starts by building Science Reference Projects, which will detail what are the foreseen observations with MOSAIC, along with observational considerations (e.g., possible choice of fields, number of visits, calibration requirements, etc.). These will be assembled into a MOSAIC red book at the end of phase B and will be used by the consortium to design Core Projects by the end of Phase D. These will be the building blocks of the MOSAIC surveys, which will be designed to adress the above science cases and provide the most transformational observations in the 2030 landscape. Important synergies with, e.g., other ELT instruments such as MICADO or HARMONI, but also with SKA are expected.

4 Conclusions

MOSAIC will provide the ELT with multi-object observations over a large patrol field, covering the optical and near-infrared wavelength range. MOSAIC is meant to be a multi-tasking instrument for the ELT and, in particular, an efficient follow-up machine for the most powerful space missions and ground-based experiments foreseen in the 2030 landscape (JWST, Euclid, Rubin, Roman, SKA, Athena and others). The MOSAIC project has started a phase B1 with ESO and is anticipating a first light in 2031-32.

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