# OPTIMOS–DIORAMAS: A Wide-field Imaging and Multi-slit Spectrograph for the E-ELT

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**We present the science, design and performance of OPTIMOS–DIORAMAS, an imager and multi-slit spectrograph for the E-ELT. It covers a wide 6.8 × 6.8 arcminute field, a large wavelength range of 0.37 to 1.6 μm, with up to ~ 500 slits observed simultaneously.**

## Science drivers

The study of first light in the Universe, the seeds of galaxies, as well as the main phases of galaxy evolution are some of the main science goals of the E-ELT, as identified in the Design Reference Mission. The sheer collecting power of the E-ELT will enable very faint objects to be observed, with a gain in performance far superior to that when the 8–10-metre class telescopes surpassed the 4-metre class. On a point source, with similar seeing, one can expect a 1.8 magnitude gain with the E-ELT compared to the VLT, or a factor of about 27 in exposure time, a considerable advantage.

However, the gain in performance is not only related to the telescope light-gathering power, but also, for many science investigations, to the capability to assemble large, statistically representative samples of stars, galaxies, AGN, or any other (rare) categories of objects in the Universe. If one is able to observe more than one object at once, the performance gain is proportional to the number of objects observed simultaneously, and a key instrument driver is the size of the field of view adapted to the science. Large wide-field imagers have been very powerful even on smaller telescopes (e.g., CFHT, VISTA, PanStarrs, soon the VST, leading to LSST), where the etendue, $A\Omega$, combining the aperture of the telescope ($A$) and the FoV ($\Omega$) is high. In spectroscopy the situation is similar, as the etendue plays an important role, but is also coupled to the multiplex, or the ability to place a high number of apertures on sky objects and collect their spectra simultaneously. In addition, the instantaneous wavelength coverage of a spectrograph also drives the performance when it is necessary to observe many spectral features or to find the redshift of a previously unknown source.

The technique of multi-object spectroscopy has matured since the 1990s, and has led to remarkable progress in our understanding of many fields of astrophysics, including galaxy and large-scale structure evolution, the dynamics of our Galaxy, clusters of galaxies, and identifying the most distant galaxies (see e.g., Lilly et al., 1995, Steidel et al., 1996, Le Fèvre et al., 2005). Multi-slit spectrographs have been the instruments of choice to push the limits of very large samples to the greatest depths. The versatile observing modes of imaging multi-slit spectrographs have become the workhorses of many observatories, like FORS1 and FORS2 and VIMOS on the VLT (Le Fèvre et al., 2003), LRIS–Keck, DEIMOS–Keck, GMOS–Gemini, IMACS–Magellan, Subaru–FOCAS, etc.

With this in mind, we have conducted a Phase A study of a wide-field multi-slit imaging spectrograph for the E-ELT (originally called OPTIMOS), which we named DIORAMAS (a diorama is a 3D scene). DIORAMAS has been designed based on the requirements of ESO for a wide-field multi-slit spectrograph in the context of the OPTIMOS study. DIORAMAS is intended to be a general purpose facility instrument, offering both deep imaging and deep multi-slit spectroscopy, over a wide field of 6.8 × 6.8 arcminutes, and a large wavelength domain from 0.37 to 1.6 μm.

We have defined test science cases to drive the requirements for a wide-field imaging spectrograph to the limits. As a first approach we have concentrated on extragalactic, high-redshift, deep observations. This is by no means limiting, as an imaging and multi-slit spectrograph of this scope is a general purpose facility with the ability to study astronomical objects from very nearby in the Solar System, Galactic programmes or ones dealing with resolved stellar population studies in nearby galaxies, up to the most distant galaxies and large surveys. One only needs to look at the programmes executed by FORS or VIMOS on the VLT to grasp the wide range of science that such instruments are capable of tackling.

Some of the main science drivers for the instrument design have been:
– extremely deep imaging in a wide field, e.g., as a means of identifying galaxy populations at all redshifts;
– the detection and study of "first light" galaxies or AGN at $z > 6$, from identifying the candidates in imaging to the secure spectroscopic redshift measurement, and to physical diagnostics enabled by spectrophotometric analysis;
– the history of galaxy mass assembly and star formation at $1 < z < 6$;
– the detection and study of the oldest galaxies at increasingly early cosmic times;
– the co-evolution of galaxies and AGN;
– the tomography of the high-redshift Universe to understand the role played by the interplay between galaxies and the intergalactic medium in galaxy formation and evolution processes; and
– the early development of large-scale structures and clustering at $z > 2$.

Even with a relatively small field of view, the E-ELT will be capable of obtaining extremely deep images in a short time, and we believe that the E-ELT should have a wide-field visible-to-NIR imager at first light. Another important element will be that the E-ELT must be autonomous in the definition of targets to be observed. It must be possible to carry out

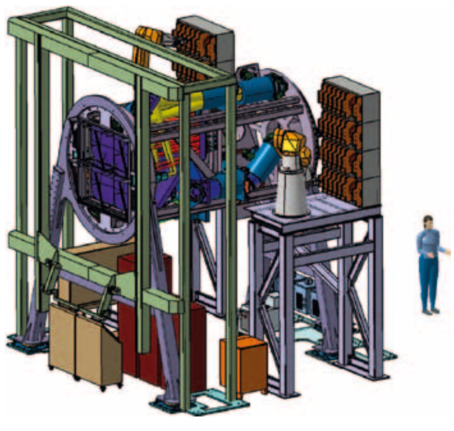

Figure 1. DIORAMAS instrument layout. The beam from the E-ELT enters the instrument from the left with slit masks (for MOS) or without (for imaging), and is then split into four channels, each with its own optical train, filters and gratings with their exchange robots, flexure compensation, detector array and dewar.

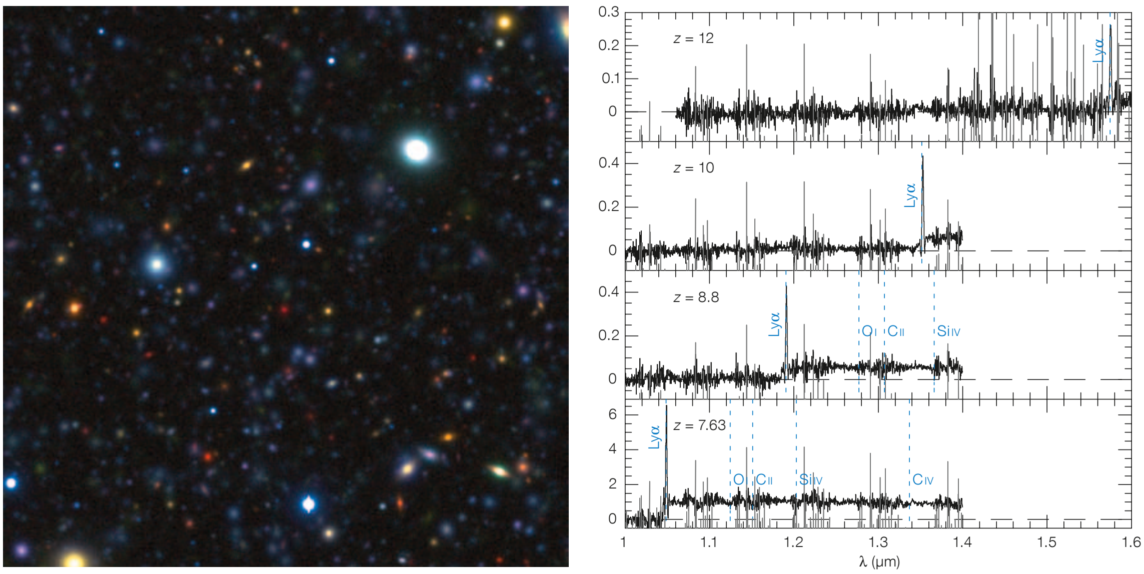


Figure 2. Left: Simulated *giJ* composite image ($AB$ ~ 30 mag) covering 1/15th of the total 44 arcminutes$^2$ FoV of DIORAMAS, as expected to be observed after 1-hour integration per filter with a 0.05 arcsecond pixel scale under 0.50 arcsecond seeing. There are about 45 000 sources in one 6.8 × 6.8 arcminute field of view. Courtesy E. Bertin. Right: Simulated spectra of young galaxies with Lyman-α emission observed from $z$ ~ 8 to $z$ ~ 12 with DIORAMAS in 4–10-hour integrations (ordinate is relative flux in $F_\nu$).

science programmes in a self-consistent manner, ie. without the necessity of relying on other facilities. Of course, the E-ELT must be capable of observing targets identified using data from other telescopes; DIORAMAS allows both, as the deep imaging capability enables the production of exhaustive source lists in photometric catalogues.

## Instrument design concept

Visible and NIR coverage has become an essential element in the observation of faint sources, as the large wavelength baseline enables many important spectral features in the spectral energy distribution to be measured, and therefore DIORAMAS offers a large instantaneous wavelength range. The instrument layout is organised around four channels, each with its own optical train, slit-masks, filters, gratings, flexure compensation, detector array and dewar, and associated hardware (Figure 1). Two channels are optimised for the visible from 0.37 to 1 μm, the two other channels are optimised for the NIR from 0.6 to 1.6 μm, cutting off before the thermal background becomes dominant. The optics provide excellent image quality and a high total instrument throughput of about 72 % excluding detector arrays. Together with a fine pixel sampling of 0.05 arcsecond/pixel, this will enable DIORAMAS to make use of the best images delivered by the telescope, particularly if the GLAO system in the telescope delivers improved images over the wide field of the instrument. Flexure is actively compensated along each of the channels using a tip-tilt actuation based on the second folding mirror in each channel. The camera of each channel focuses on a 4k × 12k pixel array of 15 μm pixels, with CCDs for the visible channels and HgCdTe arrays for the NIR. Slits are cut in metal sheets with a laser machine, with exceptional slit roughness accuracy. Masks, filters and gratings are installed/removed on the optical path using robust industrial robots. In addition, high spatial and spectral resolution integral field spectroscopy in a field of ~ 10 arcsecond$^2$ could be easily added as the instrument is conceived in such a way that it can host a slicer-based integral field unit. DIORAMAS makes use of mature and proven technology, minimising the development risk, and could therefore start being built now, and certainly could be ready by the EELT first light.

## Performance

DIORAMAS offers exceptional performance. It aims at using the field of view available at the E-ELT, with a field of view of 6.8 × 6.8 arcminute$^2$. It can perform extremely deep imaging to magnitude $AB$ ~ 28.75 (4 h, 3σ, in 1.2-arcsecond aperture) over the full FOV with a high density of sources (Figure 2, left), as well as multi-slit spectroscopy of about 480 objects at once down to $AB$ ~ 26.5 (4 h, 3σ, $R$ ~ 300, point source), or 160 objects at $R$ ~ 3000. This will allow the detection of very high redshift "first light" objects (Figure 2, right). This performance can be reached without the use of GLAO, and is comparable to that of JWST NIRCAM and NIRSPEC at 1 μm, and the best currently planned for ELTs. Using the GLAO-corrected images delivered by the telescope, DIORAMAS allows an even deeper exploration of the Universe.

## References

Le Fèvre, O. et al. 2003, SPIE, 4841, 1670
Le Fèvre, O. et al. 2005, A&A, 439, 845
Lilly, S. et al. 1996, ApJ, 460, 1
Steidel, C. C. et al. 1996, ApJ, 462, 17

Table 1. Essential instrument parameters for DIORAMAS.

| Item | Design status |
|---|---|
| Spectral range | 0.37 μm to 1.6 μm |
| Field of view | 6.78 × 6.78 arcminutes$^2$ |
| Slit size | Any width: mean 0.5 arcseconds, min.: 0.1 arcseconds |
| Pixel scale and sampling | 0.05 arcseconds per pixel |
| MOS multiplex | 480 slits of 5 arcseconds length at $R$ ~ 300<br>160 slits of 5 arcseconds length at $R$ ~ 2000–3000 |
| Spatial image quality | > 80 % encircled energy within 150 mas over 90 % FOV |
| Spectral image quality | > 80 % encircled energy within 200 mas over 90 % FOV |
| Imaging throughput | 42 % averaged over (0.37 μm, 0.43 μm); > 48 % for (0.43 μm, 0.84 μm); > 63 % for (0.86 μm, 1.60 μm) |
| Spectroscopic throughput | > 28 % over (0.37 μm, 0.43 μm); > 30 % for (0.43 μm, 0.86 μm); > 45 % for (0.86 μm, 1.6 μm) |
| Spectral resolution | $R$ ~ 300 to 2700 for visible; $R$ ~ 400 to 3000 for NIR |