OPTIMOS–EVE: A Fibre-fed Optical–Near-infrared Multi-object Spectrograph for the E-ELT

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OPTIMOS–EVE is a fibre-fed, optical-to-infrared multi-object spectrograph designed to explore the largest field of view provided by the E-ELT at seeing or GLAO-limited conditions. OPTIMOS–EVE can detect planets in nearby galaxies, explore stellar populations beyond the Local Group, and probe the physical conditions of galaxies including the most distant ones accessible with the E-ELT.

One of the major challenges in spectrograph design for the E-ELT is to build an instrument addressing some of the key, but versatile science cases of present day astrophysics. The solution is to design an instrument that samples the largest discovery space in terms of wavelength range, spectral and spatial resolutions and multiplex. OPTIMOS–EVE is unique in covering a very large space in the spectral resolution (R = 5000–30 000) versus multiplex (40–240) plane, with a large wavelength range (370–1700 nm). It also offers a unique range of apertures, including integral field units, which can be adapted to a large variety of science cases (see Figure 1). OPTIMOS–EVE aims at best exploiting the photon collection capability offered by the E-ELT. It is well suited for use in the early operational phase of the E-ELT and beyond, without a need for full adaptive optics corrections.

Table 1. Key capabilities for OPTIMOS–EVE.

Patrol field of view	7′ diameter (unvignetted), 10′ full field		
Wavelength range	370–1700 nm		
Spectral resolving power	6000	18000	30000
Number of targets	240	70	40
Apertures on sky	Single objects (0.9″); 30 medium IFUs (1.8 × 2.9″); single large IFU (7.8 × 13.5″)		
Wavelength coverage	λ/3–λ/6 (VIS); λ/10–λ/20 (NIR)		

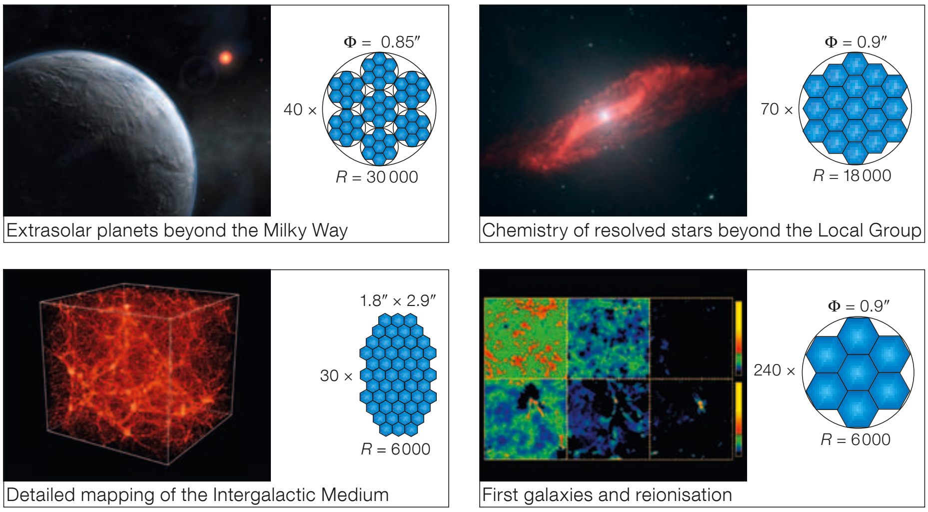

Figure 1. Four of the five science cases of OPTIMOS–EVE with, on the right of each panel, the aperture (Φ), multiplex and the spectral resolution that will be offered to study them. The 30 medium, deployable IFUs (bottom left) can provide the best sky removal and can be used for all extragalactic cases. The fifth mode of OPTIMOS–EVE is the large IFU with 13.5 × 7.8 arcsecond area for extended objects, including the 100 kpc haloes of galaxies up to z = 3.5.

Science drivers

Spectroscopy over the wavelength region accessible from the ground, from the UV to the non-thermal infrared, has been, and will remain, a key technique to investigate virtually all types of astrophysical targets. At z = 0 most of the spectral lines, fundamental for deriving astrophysical information, are found in the UV–optical range. At higher redshifts important spectral diagnostics shift into the near-infrared (NIR), and Lyman-α becomes accessible in the optical wavelength range. Due to the unique combination of wavelength coverage, multiplex and spectral resolution, most of the science that will be explored by OPTIMOS–EVE can neither be addressed by any other instrument concept under study for the E-ELT, nor by JWST instruments. OPTIMOS–EVE responds to several of the key science goals put forward by the E-ELT Science Working Group and will explore the visible to NIR wavelength region, for sources both nearby and at cosmological distances.

The OPTIMOS–EVE Phase A study Science Team explored five key science cases (see Figure 1) from which the scientific and technical requirements (see Table 1) have been derived.

Planets in the Galactic Bulge and stellar clusters, also in external dwarf galaxies. Although over 400 extrasolar planets are known, these are mostly hosted around stars in the solar vicinity. For the few distant planets, besides those around radio pulsars, the orbits and masses are unknown. On theoretical grounds, environment is expected to play a significant role in the process of planet formation. Therefore, it is important to detect and characterise planets in environments different from the solar vicinity, such as the Galactic Bulge and Local Group galaxies. With a radial velocity precision of 10 m/s for giant stars down to magnitude 20, OPTIMOS–EVE will make such a study possible and allow to be monitored up to 40 stars in each observed field.

Resolved stellar populations in nearby galaxies. With the VLT, a detailed study of the stellar populations of the Local Group galaxies has been possible. However, many galaxy types are not represented in the Local Group. In order to make further progress in our understanding of galaxy formation and evolution we need to study in detail many different types of galaxies, e.g., in the groups of Sculptor and Centaurus A. With the high efficiency, low-resolution mode of OPTIMOS–EVE and its high multiplex, the E-ELT will open up the possibility of studying the stars down to the turn-off and addressing cosmologically relevant problems, such as the lithium abundance. The medium-resolution mode, with its multiplex of 70, is well adapted for this purpose.

Tracking the first galaxies and cosmic reionisation from redshift 5 to 13. From polarisation measurements of the cosmic microwave background it appears that at $z = 10$ the Universe was already largely reionised, but little is known of the objects that powered this reionisation. The search for these "first sources" can be carried out with OPTIMOS–EVE to trace Lyman-α up to $z = 13$. The ionised gas of very distant galaxies can be far more extended than the compact distribution of stellar light. With its 240 apertures, OPTIMOS–EVE will be an ideal instrument with which to catch most of the Ly-α photons that can be diffused over relatively large areas (median 1.4 arcsecond at $z \sim 3$, see Rauch et al., 2008). Moreover the 30 medium IFUs are optimised to achieve excellent sky subtraction by sampling the sky around the target, and are thus very well suited for the first studies of the kinematics and chemistry of such primordial objects.

Mapping the ionised gas motions at large scales in distant galactic haloes. Observations of the local and distant Universe have shown that galaxies are surrounded by extended haloes of ionised gas that are the interfaces to the IGM and its enrichment with metals. The study of these haloes unravels the history of galaxy–galaxy interactions that leave recognisable signatures on the halo kinematics. OPTIMOS–EVE will be able to study galaxy haloes over the last 12 Gyr (up to $z = 3.5$).

3D reconstruction of the IGM. The space between galaxies and galaxy clusters is not empty, but is filled with a very low density warm medium that is detectable as Lyman-α absorption in the spectra of distant quasars. Although this provides a "cut-through" of the structure of the IGM along the line of sight, nothing is known about its transverse structure. Cosmological simulations suggest that the IGM has a filamentary structure, where filament crossings correspond to the locations of galaxy clusters. OPTIMOS–EVE will provide sufficient resolution and sensitivity to use Lyman-break galaxies of magnitude 25 as background sources. These galaxies have a sufficient spatial density to allow a real 3D reconstruction (tomography) of the IGM, which may be directly compared to cosmological simulations.

The OPTIMOS–EVE targets will be selected from imaging observations obtained with other telescopes, and many OPTIMOS–EVE studies will significantly benefit from complementary observations with JWST, ALMA and Gaia.

Instrument design concept

OPTIMOS–EVE has been designed for the E-ELT Nasmyth focus. The fibre-positioner provides the opportunity to observe up to 240 single targets within the ≥ 7 arcminute FoV, or to combine the fibres into medium- or large-sized IFUs. Astrophysical sources have many different apparent sizes on the sky, ranging from unresolved stars to ≥ 10 arcsecond extended sources, even at high redshift. For point sources the aperture has been optimised to 0.9 arcseconds; the IFUs are matched to the size of $z \geq 1$ galaxies. The fibre/positioner approach provides the advantage of avoiding flexure issues when invoking such a large physical field of view (> 2 m diameter). A spectral resolving power > 5000 is mandatory in the NIR to provide enough spectral regions that are not affected by strong OH skylines. The wavelength coverage of an individual spectrum ($\geq \lambda/3$ to $\geq \lambda/6$ in the visible and $\geq \lambda/10$ to $\geq \lambda/20$ in NIR) is a trade-off between spectral resolution, multiplex and detector cost. Sky correction is a crucial issue, especially for the detection of faint sources that are in reach of the E-ELT. It is often believed that fibre-fed spectrographs have difficulties performing robust sky corrections. However a large number of sky-fibres will be used to sample the temporal sky variations over the whole field of view, and other possible effects can be overcome by calibrating the fibre throughput and using beam-switching.

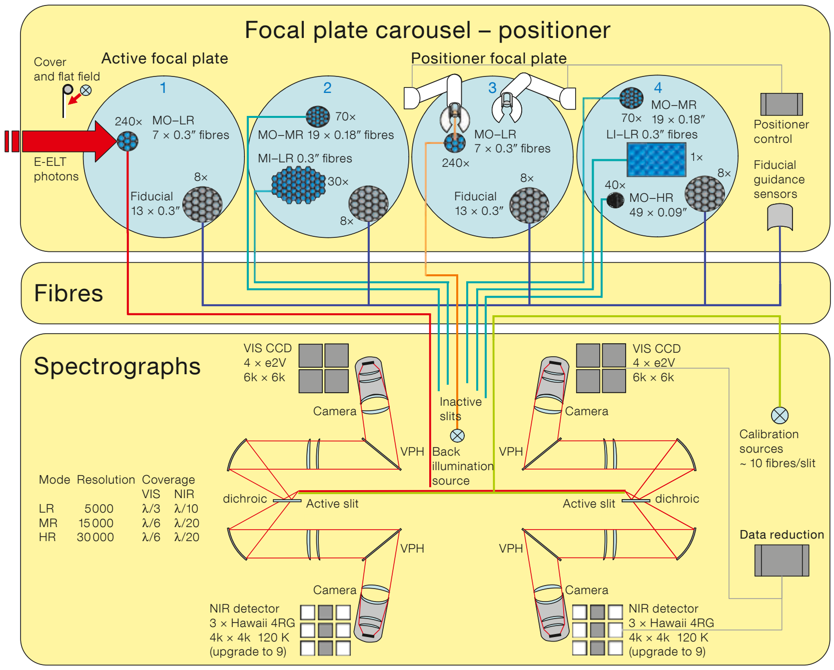

Figure 2. Schematic overview of OPTIMOS–EVE. The three main subsystems of the instrument are clearly indicated: the focal plate carousel-positioner, containing four focal plates with various single object fibre inputs and IFUs as well as a robot positioner; the fibres, to transport the collected light to the spectrograph, guidance sensors and from the calibration source; the spectrographs, consisting of a visible arm and a NIR arm, separated by a dichroic. The dispersing elements are VPH gratings.

The instrument design (Figure 2) includes a focal plate carousel and fibre positioner feeding two dual-beam VIS/NIR optimised spectrographs. The spectrographs employ VPH gratings in first order for optimal performance. The concept and operability are based on FLAMES/GIRAFFE and X-shooter; it is a robust instrument, which can be developed, manufactured and integrated using existing technologies.

Performance

A few examples of instrument performance among the science drivers are presented. For diffuse Ly-α sources, the use of fibres on the sky to map temporal sky variations, allows the detection with S/N = 8 for fluxes of 10^{-19} erg s^{-1} cm^{-2} in 40 hours. Galaxy halo kinematics to $z = 3.5$ can be studied in 10 hours per galaxy. Observation of multiple Ly-α emitters with the IFUs at $R = 6000$ for IGM studies enables a continuum S/N from 30 to 50 to be reached in 10 hours exposure.

References

Rauch, M. et al. 2008, ApJ, 681, 856

Links

http://www.OPTIMOS-EVE.eu