# EPICS: An Exoplanet Imaging Camera and Spectrograph for the E-ELT

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**EPICS is an instrument project for the direct imaging and characterisation of exoplanets with the E-ELT. The instrument is optimised for observations in the visible and the near-infrared and has photometric, spectroscopic and polarimetric capabilities.**

## Science drivers

By about 2015, radial velocity surveys and the Kepler satellite will have provided a very good statistical answer to the crucial question of how frequent exoplanets in close orbits are around main sequence stars. These data will be complemented by the VLT SPHERE and Gemini GPI planet-finding instruments for self-luminous giant planets in outer orbits around young stars. Spectroscopic data are being obtained for transiting planets and additional data will be obtained for self-luminous giant planets. However, with the current and planned space instrumentation, the capability to study the physical properties of exoplanets comprehensively, and in particular their chemical composition, remains limited. The contribution of EPICS will be unique and transformational in various areas of exoplanet research:
- Detection of low-mass and wide-orbit planets to explore the mass–orbit function. Detections of exoplanets at angular separations larger than several AU with other techniques (e.g., transits with Kepler and Plato; radial velocities with CODEX) are inefficient.
- Characterisation of exoplanets down to the size of rocky planets by direct imaging, spectroscopy and polarimetry. Almost all nearby exoplanets detected by radial velocity or astrometric techniques can only be characterised in larger numbers by direct imaging, since the probability for transits for larger orbital separations is low. In addition transit spectroscopy needs a fairly low exoplanet/star contrast of the order $10^{-5}$, limiting the method to rather tight orbits.
- Detection of very young planets (age ~ $10^7$ yr or less) close to the ice-line in order to test planet formation and evolution models and to understand the processes driving planet formation. Only EPICS will provide access to the small angular separations (~ 30–50 milliarcseconds) required to observe giant exoplanets forming at the ice-line around pre-main sequence stars in the closest star-forming regions and young associations. Other techniques have limitations: space telescopes have too low an angular resolution; radial velocity studies suffer from stellar noise of the active young stars; long time frames are needed to follow a 3–5-AU orbit at the ice-line; the probability of catching a transit event of an object orbiting at the ice-line is virtually zero.

In addition, EPICS will make optimal use of the unique light-collecting power and angular resolution provided by the E-ELT. Its spectroscopic and polarimetric capabilities, as well as the AO performance providing diffraction-limited images even at optical wavelengths with angular resolutions down to 5 milliarcseconds (mas), will have a substantial impact on a large variety of astrophysical fields from studies of the Solar System and circumstellar discs to stellar astronomy and physics. Differential polarimetry at optical wavelengths will allow circumstellar debris discs to be imaged several orders of magnitudes fainter than the ones around ßPic or HR 4796 and at 10 mas resolution, to study the dynamic interaction of the disc with the embedded exoplanets.

In order to deliver these science goals, EPICS fulfills the following main requirements:
- The systematic intensity contrast between the exoplanet and the host star is better than $10^{-8}$ at 30 mas and $10^{-9}$ beyond 100 mas angular separation.
- Spectroscopic and polarimetric imaging, as well as medium resolution spectroscopy ($R$ ~ 3000) for the spectral characterisation of exoplanet chemistry is provided.
- The spectral range covers the optical to the NIR between 600 and 1650 nm.

## Instrument design concept

The key to achieving the highest imaging contrast and sensitivity from the ground is a superb correction of the dynamic and quasi-static wavefront aberrations introduced by Earth's atmosphere and the telescope/instrument, respectively. In order to correct for dynamic aberrations and to suppress the atmospheric turbulence residual halo to about $10^{-5}$ at small angular separations and to better than $10^{-6}$ close to the adaptive optics correction radius, EPICS implements a high-order (or extreme) AO (called XAO) system using a roof-pyramid wavefront sensor.

All optics moving or rotating during an observation, such as atmospheric dispersion compensators or optical de-rotators, will be seen by XAO and the instrument elements, i.e., they will be placed in the common path (see Figure 1). Hence, EPICS will have excellent temporal stability of instrumental aberrations. Non-common path optical aberrations will be calibrated by focal plane wavefront sensing techniques and off-loaded to the XAO system. The diffraction pattern will be suppressed by apodisers and coronagraphs. As a result EPICS will achieve a high quasi-static point spread function (PSF) contrast of better than $10^{-6}$.

XAO and quasi-static PSF residuals are further calibrated and removed through instrumental and data analysis techniques such as spectral deconvolution with the NIR IFS (integral field spectrograph) and differential polarimetry with the optical polarimeter EPOL. These techniques will provide the required systematic contrast of the order $10^{-8}$ at 30 mas to better than $10^{-9}$ at larger angular separations. This last step of PSF residual calibration will be made possible through an optimisation of the instrument optics (Figure 1) for maximum efficiency of the speckle calibration techniques: i) a small and well-known speckle chromaticity is provided by a design that minimises amplitude aberrations introduced by the Fresnel propagation of optical errors; and ii) a small instrumental polarisation is provided by design, by avoiding large angle reflections and with a careful choice of coatings.

The IFS will provide a field of view of 0.8 × 0.8 arcseconds sampled by 2.33 mas spaxels at the diffraction limit at 950 nm. The spectral range is 950–1650 nm, and the 2-pixel spectral resolution is 125 in the main observing mode. In addition, the IFS offers two higher spectral resolution modes with $R$ ~ 1400 and $R$ ~ 20 000 with a smaller slit-like FoV of 0.8 × 0.014 arcseconds. EPOL provides a FoV of 2 × 2 arcseconds sampled by 1.5-mas spaxels at the diffraction limit at 600 nm for differential or classical imaging and polarimetry through various astronomical filters in the optical.

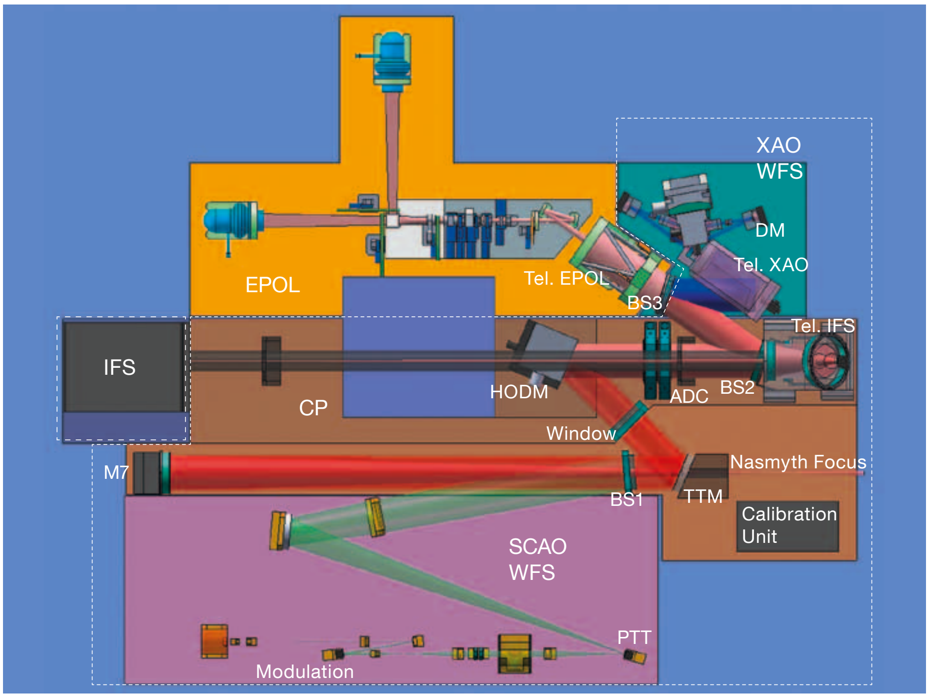



Figure 1. Top view of the optomechanical concept for EPICS.

Figure 2. Cuts along the *x*- and *y*- directions (full and dashed lines respectively), with distance in arcseconds, of the 2D contrast maps for an *I* = 2.3 mag. G2 star (10-hour exposure with field rotation) are shown for the EPICS modes IFS (left) and EPOL (right).

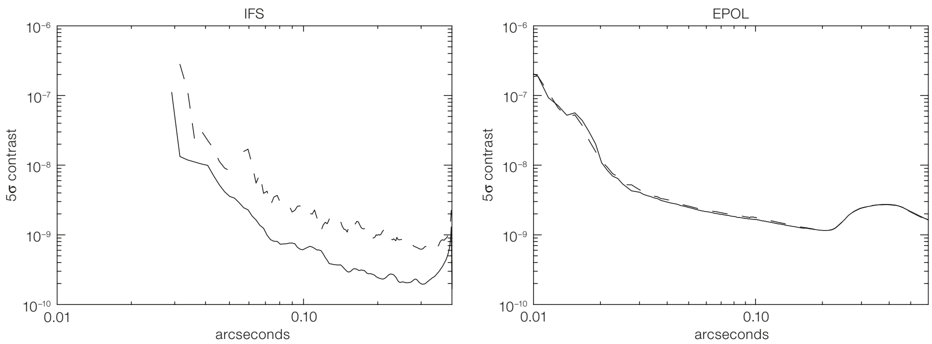
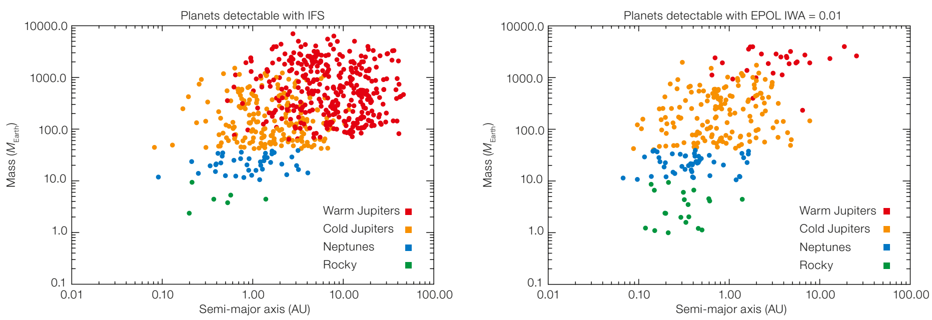



Figure 3. EPICS detections predicted by MESS for the IFS (left) and EPOL (right).




## Performance

In order to design EPICS and evaluate its performance, considering as many real-life error sources as possible, the following tools were developed: i) an end-to-end model of the instrument called PESCA (Parallel EPICS Simulation Codes and Applications); and ii) a Monte Carlo code called MESS to estimate the scientific output.

Combining the XAO residuals with assumptions on object brightness, E-ELT wavefront and amplitude errors and pupil geometry as well as instrument aberrations, throughput, diffraction suppression systems and data analysis, PESCA provides final contrast curves such as the ones shown in Figure 2. These contrasts demonstrate that EPICS is pushing the systematic limits below the photon noise level for virtually all possible targets with the IFS and EPOL. It therefore achieves photon-noise-limited contrast levels of the order $10^{-9}$ at separations around 0.1 arcsecond required to observe exoplanets in reflected light. The lower number of photons available for EPOL when compared to the IFS (taking planet polarisation < 30 % and for a smaller spectral bandwidth) and the higher AO residuals at optical wavelengths, make EPOL less sensitive than the IFS at larger angular separations. The use at shorter wavelengths and the efficient apodised Lyot coronagraph, however, allow EPOL to achieve high contrast at the smallest angular separations down to 10 milliarcseconds.

The PESCA contrast curves are then used to analyse the discovery space of EPICS with MESS, comparing expected properties of a population of exoplanets with the detection limits. MESS models stellar parameters (mass, distance, age, etc.) from samples of real stars, and models planet populations using theoretical models and observational results.

Figure 3 shows the EPICS detection rates predicted by MESS applied to a large sample of nearby or young stars. While the IFS generally achieves a better photon-noise-limited contrast and has higher detection rates on Neptune-like and giant planets, the very small inner working angle of EPOL allows it to detect several rocky planets that cannot be accessed by the IFS. Besides the detection capabilities of IFS and EPOL, the two instruments are also highly complementary in their characterisation capabilities and offer a variety of secondary science cases, e.g., the observation of circumstellar debris discs with EPOL at the highest angular resolutions.