# Defining the MOSAIC GLAO image quality budget

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**Abstract**

MOSAIC is the ELT wide-field spectrograph capable of observing over 200 targets simultaneously within an AO-corrected 7.4 arcminute diameter field of view (FoV) across a wavelength range of 400-1800nm. The instrument has a highly-modular design to accommodate the multiplex capability between the various observation modes, which is a significant difference from other ELT instruments. The accessible FoV spans a diameter of up to 10 arcminutes, and this large area is what enables the multiplexing capability. Accordingly, the requirements for the AO correction is specified in terms of enclosed energy (EE) appropriate for spectrometer inputs: spectrograph fibres which are illuminated via a relay at the focal plane, or the IFU input apertures which are also re-imaged from the focal plane via relay optics.
To increase the EE into the apertures of either sub-system, GLAO is the only technology which can cover the FoV required for the focal-plane fibre-illumination. Although the IFUs could utilise MOAO–due to their limited number, this would be feasible–it has been found that GLAO delivers sufficient performance to meet the specifications. Therefore GLAO is the only AO mode designed for MOSAIC and the instrument controls M4/M5 to correct the entire FoV over the ELT NoAO mode, which is the telescope-delivered PSF after the Pre-Focal Station. The baseline GLAO conceptual design is to use 4 LGS WFSs to derive the high-order wavefront measurements and three guiding sensors to correct for residual instrument–telescope distortions (internal and Nasmyth flexure) and focal plane image distortions directly from the telescope e.g. field rotation from M4 to M5 tip/tilt off-loads, to give one example.

We assume that a conventional simulation (MC or Fourier) is sufficient to produce GLAO correction which is compatible with the design i.e. the correction over NoAO is equivalent to the conventional simulation correction over seeing-limited. This then implies all fast residual vibrations are eliminated, leaving the AO residual wavefront and any slow vibrations. These slow vibrations are corrected for by the guiding sensors, and so slow vibrations and focal plane distortion is modelled by additional convolutions or linear transforms of the PSF, depending on the longevity/time-scale of the effects. For modelling the image quality, the focal plane distortions are not relevant as we assume the instrument can measure and then offset apertures to account for these errors: over an hour, estimated to be 540mas. The errors that cannot be measured in the same situation are estimated to be 51mas. For context, the FWHM of the NoAO PSF is estimated to be 550mas at a wavelength of 1650nm, and for the seeing-limit the FWHM is 600mas.

Our PSF model begins with a static, long-term GLAO-corrected PSF as the image delivered

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to the focal plane. The relay optics to the final spectrograph fibres and the IFU apertures can add additional aberrations, always reducing the EE. Therefore given a AO-simulation EE and PSF at the focal plane, the EE at the final apertures needs to be quantified. Unlike Strehl, the WFE is insufficient to define EE as the wavefront cross-correlation is relevant: differences in EE for equal WFE from adding various Zernikes relative to adding just tilt (Z2/3) often exceed 10% and even reach 50% for some modes. Therefore modelling the aperture's EE requires a more detailed set of parameters than just WFE. To formally define EE, given a statistically averaged PSF, we can use the OTF as part of the calculation: the EE is an integral of the pupil's OTF multiplied by both the Fourier transform of the EE aperture and by an exponential factor that represents residual, homogenous phase aberrations which need not be isotropic (there is field-dependency from M4's non-pupil conjugation.) To use this to calculate EE with additional aberrations implies calculating the exponential factor–from the simulation's residual power-spectra for example–and then modifying the pupil OTF to include the additional aberration and introducing the EE aperture term above before integration.

The complexity of this OTF approach–which nonetheless allows a pre-defined AO PSF to be used in a calculation–has led us to consider alternatives by parameterising the EE calculation. First, a convolutional direction which models EE degradation by convolving the AO-corrected PSF with a kernel which is defined for various well-known aberrations. Second, simplifying the OTF-based EE calculation by conversion to a 1D equivalent by averaging azimuthally. Finally we examine approaches to even simpler parameterisation. Bringing the above together, we discuss the potential routes to calculating the image quality budgets for MOSAIC GLAO and difficulties we encounter in simplification to make the process usable within the consortium for the system engineering and design processes.

**Keywords:** GLAO, MOSAIC, ELT, image quality, EE, enclosed energy, simulation