

Properties of the focal stations of the Euro50

Mette Owner-Petersen

Lund Observatory, Box 43, 22100 Lund, Sweden, E-mail: mette@astro.lu.se

Abstract: This paper describes the optical and mechanical properties of the focal stations of the Euro50. Basic optical properties are given in the form of focal ratio, plate scale, angular resolution (seeing or diffraction limited), field of view and radius of curvature of the focal station in question. For the focal stations provided with AO control, examples of expected performance related to the Strehl ratio and the shape of the pointspread function is provided. Mechanical properties are given as the dimensions of the space available for instrumentation.

Keywords: Extremely large telescopes, Adaptive optics

1. GENERAL INFORMATION OF THE EURO50

Euro50 is a proposed optical telescope with an equivalent primary mirror diameter of 50 m. The concept has been developed in collaboration between institutes in Sweden, Spain, Ireland, Finland and the UK. The core telescope has an aplanatic Gregorian configuration with an adaptive secondary and a hexagonal segmented primary. Both mirrors have an elliptical shape. The first Gregorian focus is intended for operation in single conjugate adaptive optics (SCAO) mode. The basic aplanatic configuration is followed by an Offner-like three-mirror relay system comprising a second plane adaptive mirror conjugate to an altitude of 10 km. The final focus is intended for operation in dual conjugate adaptive optics (DCAO) mode providing a larger corrected field. The principal features of the layout are shown below in Figure 1. For the present, AO corrected operation is only planned in the K-band, but an upgrade to the V band is foreseen in the future.

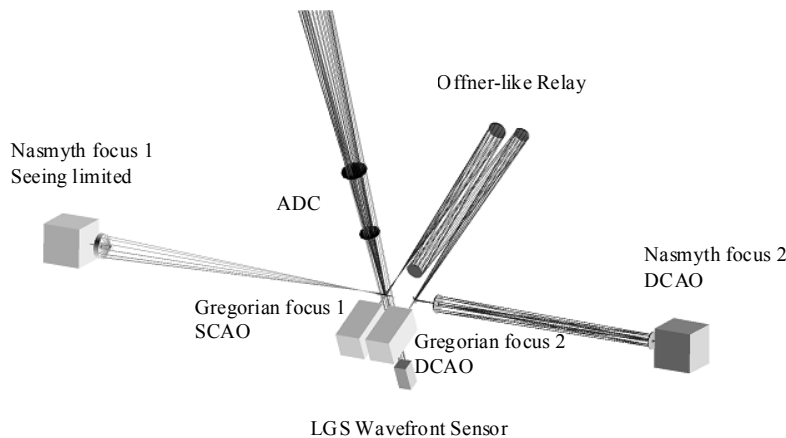


Figure 1: Optical layout of the Euro50 showing the various focal stations

Apart from the Nasmyth focus 1 shown in Figure 1, the Euro50 offers the possibility of seeing limited operation in the prime focus just following the main mirror. In order to achieve a sufficient FOV, this focus can be equipped with a corrector consisting of a clamshell mirror configuration followed by a doublet. The corrected focus can be accessed without removing the adaptive secondary. The prime focus corrector is shown in Figure 2.

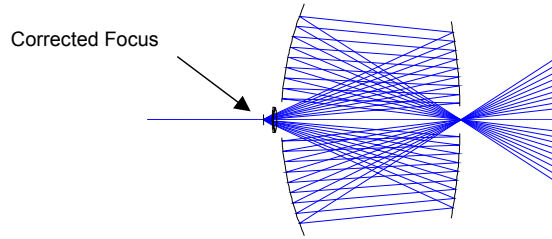


Figure 2: Optical layout (Zemax) of the prime focus corrector

Between the adaptive secondary and the first Gregorian focus there will/may be a linear atmospheric dispersion compensator (ADC) consisting of two thin wedges of which the upper one will be movable^[1,2]. This design was originally conceived by Beckers et al for two of the 8 m VLTs^[3]. The operational principle of the ADC is sketched in Figure 3.

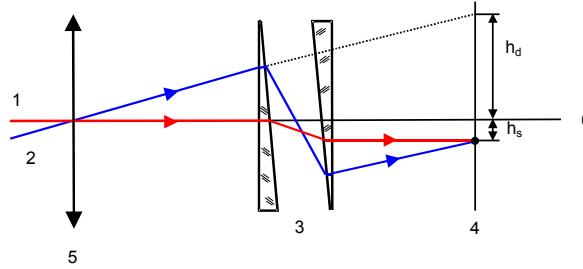


Figure 3: Operational principle of the ADC.

1: Red ray. 2: Blue ray. 3: Intermediate cross point. 4: Telescope focal plane. 5: Telescope pupil. 6: Optical axis. h_d : Linear dispersion. h_s : Focus shift. The wedge separation is highly compressed in the drawing.

When used in combination with the deformable secondary for aberration compensation, a preliminary Zemax design^[1,2] shows that this ADC may provide diffraction limited image quality for zenith angles smaller than 45° within the classical spectroscopic bands for a motion range of about 0-3 m of the upper wedge. For zenith pointing, the wedges will be close together and the main aberrations will be defocus and spherical aberration. Moving away from zenith, the rotational symmetry will be broken resulting in additional field coma and field astigmatism, which can be corrected on the deformable secondary. Apart from the geometrical aberrations, there will be a wavelength dependent residual tilt (secondary spectrum), which is the main culprit for restricting the corrected bandwidth to the classical spectroscopic bands shown in Table 1. The maximum feasible diameter of 1.2 m of the wedges (and of the main beamsplitter) restricts the FOV of the first Gregorian focus to 4° .

Table 1: Linear atmospheric dispersion at the ORM site for $z = 45^\circ$

Band	λ Range (μm)	ΔR (arcsec)	$\Delta R/d_A$		
			D = 30 m	D = 50 m	D = 100 m
U	0.331-0.399	0.850	139	231	462
B	0.391-0.489	0.730	98	163	326
V	0.505-0.595	0.290	31	52	104
R	0.59-0.81	0.350	30	50	100
I	0.78-1.02	0.190	13	21	42
J	1.06-1.44	0.110	5.2	8.7	17
H	1.50-1.70	0.023	0.8	1.4	2.8
K	1.96-2.44	0.018	0.5	0.8	1.6
L	3.05-3.75	0.011	0.2	0.3	0.6
M	4.9-5.5	0.007	0.06	0.1	0.2

Table 1 shows that the Euro50 may not need the ADC for K, L and M band operation, but it surely will be needed for shorter wavelengths.

The Euro50 concept is presented in more details in “Euro50, Design Study of a 50 m Adaptive Optics Telescope”^[1] and in “Extremely Large Telescopes, Optical Design and Wavefront Correction”^[2].

2. OPTICAL PROPERTIES OF THE EURO50 FOCAL STATIONS

As shown in Figure 1 the Euro50 will provide relays of the two basic Gregorian foci to Nasmyth platforms. The following tables 2, 3, 4, 5 and 6 show the focal ratio, the plate scale, the angular resolution (λ/D or seeing limited), the field of view and the radius of curvature of the image plane at the two Gregorian foci, the two Nasmyth foci and the corrected prime focus.

Table 2: Gregorian focus 1 (see Figure 1)

Name	Value
Focal Ratio	F/13
Plate Scale	3.15 mm/arcsec
Angular Resolution (K-band)	0.0091”
Field of View	4’ (10’) = 0.756 m (1.89 m)
Radius of Curvature	3.6 m

The Gregorian focus 1 is intended for SCAO using the deformable secondary. Wavefront sensing can be achieved using either Sodium beacons (SB) or in a ground layer adaptive optics (GLAO) mode, where wide field natural guide stars may be picked up within a 10’ field. In the SCAO mode wavefront sensing will be achieved using 13 SB emulating an axial natural guide star (NGS). As mentioned previously the ADC and the main beam splitter restrict the field to 4’, so the GLAO mode requires both to be removed. Since the basic design is an aplanatic Gregorian, the main aberration within the 10’ FOV is astigmatism, which restricts the RMS image spot size to 0.5” at the field edge. Hence each natural guidestar (NGS) will require its own corrector for astigmatism (a cylinder lens) and its own ADC.

Table 3: Gregorian focus 2 (see Figure 1)

Name	Value
Focal Ratio	F/20
Plate Scale	4.85 mm/arcsec
Angular Resolution (K-band)	0.0091”
Field of View	4’ = 1.16 m
Radius of Curvature	2.6 m

The Gregorian focus 2 focus is intended for DCAO using both the deformable secondary and the planar DM conjugate to 10 km altitude (see Figure 1). Wavefront sensing will be achieved using SBs. Preliminary investigations indicate that 37 SBs will be needed to adequately emulate 5 NGSs in a cross with 30” arms, but it should be pointed out that the needed number of SBs and the control strategy (least squares or tomography) is an open question, which must await the result of simulations.

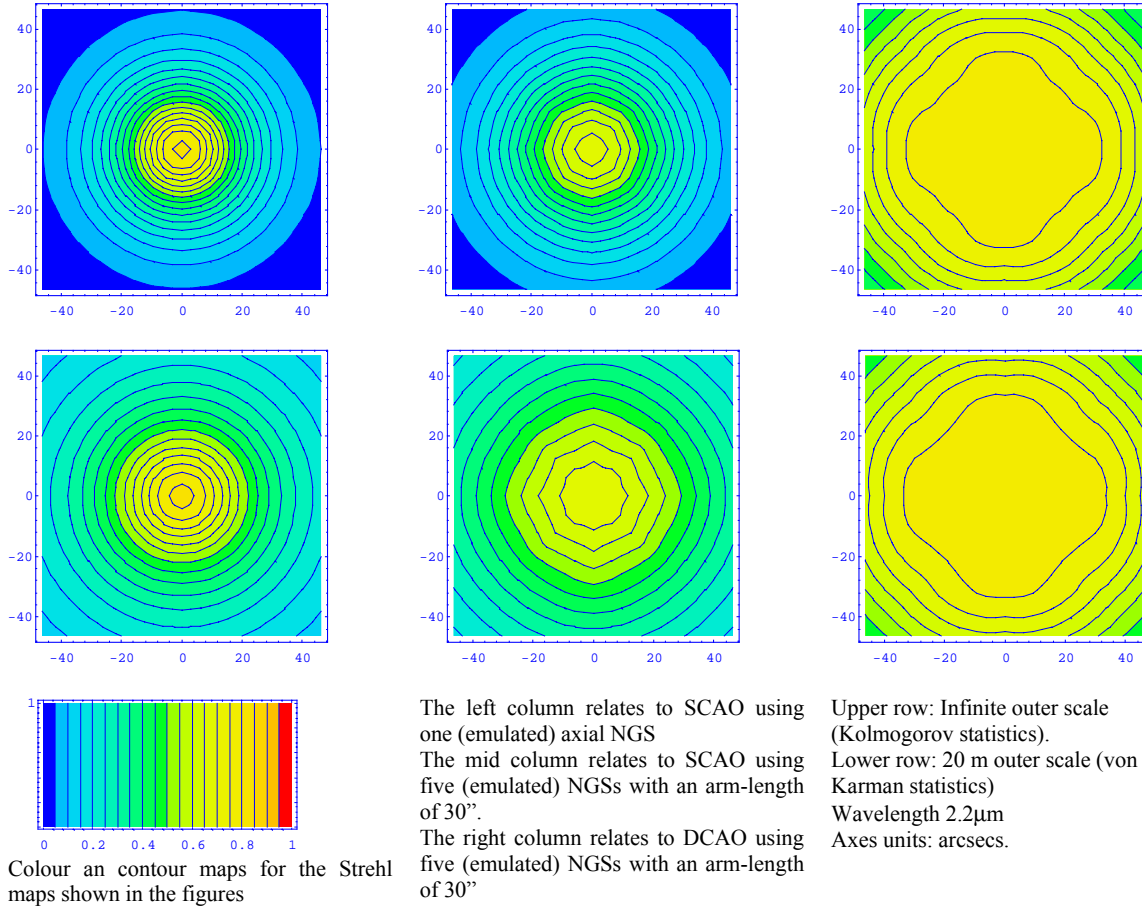


Figure 4: Analytically evaluated Strehl performance in the SCAO and DCAO modes

Figure 4 shows the K band performance letting 13 respectively 37 SBs emulate either 1 axial NGS or 5 NGS in a cross with an arm length of 30"^[4]. The figure shows analytically calculated average Strehl maps as function of field angle in arcseconds. Only anisoplanatism and the fitting error were accounted for in the calculations, which were performed assuming a standard seven-layer model of the ORM atmosphere. Note the importance of the outer scale for the predicted Strehl performance. It should be emphasized that wavefront sensing using Sodium beacons for the present will not work for V-band correction. The reason is that the spot elongation for a 50 m telescope will be around 9" in the outermost subapertures if the launcher is placed behind the secondary. This exceeds the V-band isoplanatic angle of around 5". Unless a pulsed laser having a power sufficient for gated SB detection can be constructed, this problem cannot be solved.

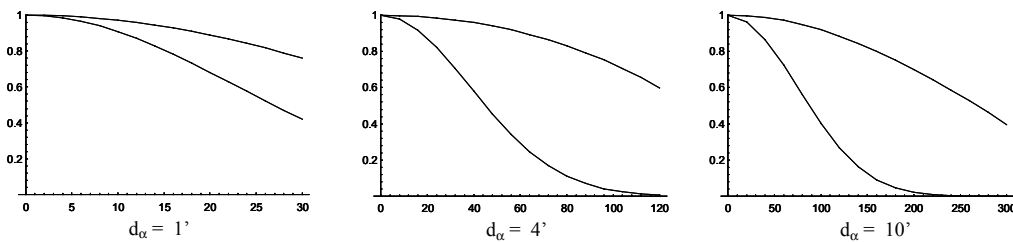


Figure 5: Normalized Strehl ratio as function of field angle for three different NGS ring diameters d_α . x-axis units: arcsecs. Upper curves: 20 m outer scale Lower curves: Infinite outer scale. Wavelength 2.2 μ .

In order to evaluate the expected K-band performance in the GLAO mode using NGSs, a somewhat artificial guide star configuration, namely a continuous ring of diameter d_α , was adopted for calculations^[5]. Figure 5 shows the normalized Strehl ratio as function of angle in arcseconds for ring diameters of 1', 4' and

10'. Figure 6 shows the point spread function (PSF) profile for an axial star. Note that the relative Strehl performance is quite homogeneous within a FOV of half the ring diameter in the case of 20 m outer scale

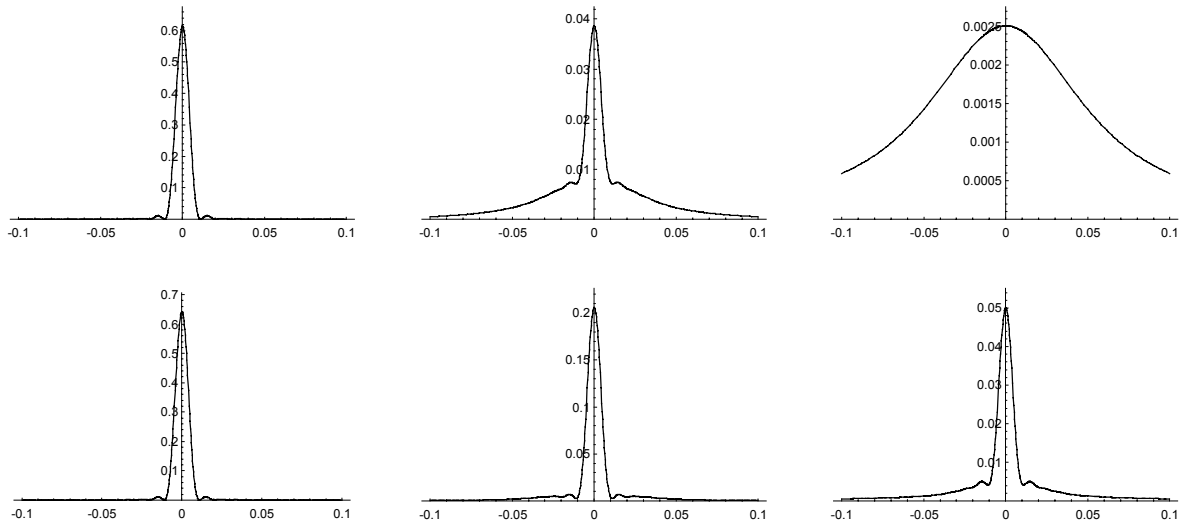


Figure 6: Axial PSFs normalized to peak-value 1 in the diffraction limited case. x-axis units: arcseconds. Left column: $d_\alpha = 1'$. Middle column: $d_\alpha = 4'$. Right column: $d_\alpha = 10'$. Wavelength $2.2 \mu\text{m}$. Upper row: Infinite outer scale. Lower row: 20 m outer scale.

The Nasmyth focus 2 (properties shown in Table 4) is just the Gregorian focus 2 relayed along the elevation axis to a Nasmyth platform. It is intended for DCAO operation and shows the expected performance characteristics depicted in the right column of Figure 4 (only anisoplanatism and fitting error).

The (preliminary) relay optics to the Nasmyth focus 1 (properties shown in Table 5) is designed as a two-mirror corrector located at the end of the elevation axis. This design is responsible for the quite small field, which is limited by vignetting. In case a larger FOV is wanted, a design based on refractive relay optics and providing a smaller focal ratio will be better.

Table 4: Nasmyth focus 2 (see Figure 1)

Name	Value
Focal Ratio	F/16
Plate Scale	3.88 mm/arcsec
Angular Resolution (K-band)	0.0091''
Field of View	4' = 0.931 m
Radius of Curvature	-2.08. m

Table 5: Nasmyth focus 1 (see Figure 1)

Name	Value
Focal Ratio	F/5
Plate Scale	1.21 mm/arcsec
Angular Resolution	0.5''
Field of View	2' = 0.145 m
Radius of Curvature	-0.145 m

Table 6: Prime corrected focus (see Figure 2)

Name	Value
Focal Ratio	F/1
Plate Scale	0.242 mm/arcsec
Angular Resolution	0.5''
Field of View	8' = 0.116 m
Radius of Curvature	Flat

The prime corrected focus (properties shown in Table 6) is the main focus foreseen for seeing-limited operation. The focal ratio $F/1$ provides an excellent match to current CCDs. One problem must be addressed: Since the primary mirror edge sensor system does not sense tilt and curvature, there must be a wavefront sensor operating on a picked-off star for controlling tilt and curvature of the primary.

Apart from the focal stations and operational modes described here, there might be two other items of interest: The most ambitious goal of AO is related to direct observation of Earth-like planets belonging to other stars in our galaxy. This will require so-called extreme adaptive optics (ExAO) in which the mother-star is used for wavefront sensing and only the adaptive secondary is used for wavefront correction. Although apparently simple, the request for extremely low background levels of $10^{-9} - 10^{-10}$ in the PSF-halo puts severe demands on the optical design, which must include both a rejection of the central core of the star image (to prevent spill-over in the CCD) and an apodization of the pupil (to suppress the side-lobes of the stellar PSF). The Gregorian focus 1 may be a suited starting point for relay-optics providing the needed filtering operations, but so far no optical design has been implemented and analyzed for the Euro50. Observations in the sub-millimeter range may also be feasible with the Euro50. Taking a typical wavelength of 0.2 mm (1.5 THz), the resolution (λ/D) will be 0.825" corresponding to 2.6 mm in the Gregorian focus 1. If bolometric arrays with a pitch of this size can be built, this mode of operation may be an option.

3. MECHANICAL PROPERTIES OF THE EURO50 FOCAL STATIONS

Referring to Figure 1 and Figure 7 each of the focal stations provides for a box shaped volume to accommodate instrumentation. Relevant measures in meters are listed in Table 7

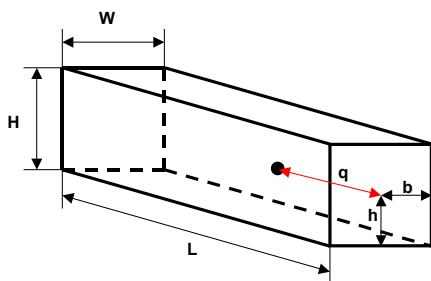


Figure 7: Instrumentation volume.

Arrow q: Optical axis. Black dot: Axial focus.

Table 7: Dimensions of the instrumentation volumes (see Figure 7)

Name	H	W	L	q	h	b
Prime Focus	2.8	2.8	1.0*	<0.8	1.4	1.4
Greg. Foc.1 (bent)	1.5	1.5	23	<1.5	1.5	***
Greg Foc.1 (GLAO)	2.8	2.8	2.0	<2.0	1.4	1.4
Greg. Foc. 2	1.5	1.5	23	<2.0	1.5	***
Nasmyth Foc.1	12	30	17	<0.5	4.5**	15
Nasmyth Foc.2	12	30	17	<0.5	4.5**	15

(*): The quoted length L of the corrected prime focus volume is for the case that the secondary is not removed. (**): Height h measured relative to Nasmyth platform. (***): Separation of the two optical axes is 2.29 m (see Figure 4). In the present mechanical design the cross-section of the elevation tunnel is 3x3 m².

REFERENCES

1. T. Andersen, A. Ardeberg and M. Owner-Petersen (eds), *Euro50. A 50 m Adaptive Optics Telescope*. Lund Observatory, 2003 ISBN91-631-4317-8.
2. A. Goncharov, *Extremely Large Telescopes. Optical Design and Wavefront Correction*. Lund Observatory 2003 ISBN 91-628-5607-3 73 (1948), 803.
3. G. Avila, G. Rupprecht and J. M. Beckers, *Atmospheric Dispersion Correction for the Focal Reducers at the ESO VLT*. SPIE Proc. Vol.2871, 1996, pp 1135-1143
4. M. Owner-Petersen, T. Andersen, A. Goncharov and J. M. Beckers, *Control Strategy for the Adaptive optics of the Euro50*. SPIE Proc. Vol. 4840, 2002, pp 427-435
5. M. Owner-Petersen and A. Goncharov, *Performance Analysis of the Improved Seeing Limited Mode for the Euro50*. SPIE Proc. Vol 5382, 2003, pp 544-549