Performance of a NGS-based MCAO demonstrator: the NGC3366 and NGC2346 simulations

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D. Bello[a], R. Conan[b], B. Le Roux[a], E. Marchetti[b], J.M. Conan[a], T. Fusco[c], A. Tokovinin[d], M. Le Louarn[e], E. Viard[f] and N. Hubin[b]

[a]ONERA, Département d'Optique Thérorique et Appliquée, B.P. 72, 93322 Châtillon Cedex, France
[b]European Southern Observatory, Karl Schwarzchild Str. 2, D–85748 Garching bei München, Germany
[c]Observatoire de Meudon, France
[d]Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile
[e]Center for Adaptive Optics, Kerr Hall, University of California, Santa Cruz, CA, 95064, USA
[f]Astronomical Observatory of Padova, vicolo dell'Osservatorio 5, I-35122 Padova, Italy

ABSTRACT

Multi–conjugate adaptive optics [MCAO] is announced as the next generation of adaptive optics systems [AOS]. MCAO will be almost mandatory for extremely large telescopes [ELTs] because it permits to compensate the corrugation of the phase of the wave front on a larger field–of–view than can be done with classical AOS. At the same time, MCAO allows to extend the sky coverage that can be obtained employing natural guide stars. So, it is important to know which performances can be expected from MCAO for the 8–10m class telescopes when using natural guide stars.
We give here the expected performances of an MCAO systeme on 8–10m telescopes from the point of view of imagery and spectroscopy over two real extended objects, NGC3366 and NGC2346. The performances are evaluated with the calculation of the Strehl ratio [SR], the full-width-half-maximum [FWHM] and diameter that encircles the 50% of the energy. These quantities are computed using a measured C_n^2 profile and for asterisms of natural guide stars [NGSs].

1. INTRODUCTION

Several classic adaptive optics systems are now working on a large number of ground based telescopes. These systems provide corrected images in a field of view that does not exceed the size of the isoplanatic patch. This is sufficient for a large number of scientific programs, but there are others that would benefit from having wide field near diffraction limited images. We have identify the HII regions in galaxies and the shock boundaries at planetary nebula as regions that would benefit from wide field corrected images. The study of the images could provide information for the analysis of the morphology of the source as well as the history of the object. On the other hand, in spectroscopy, the study of emission lines provides a useful tool for many aspects of the study of the object. The dynamical behaviour of the source can be studied from the shape and width of their emission lines, and their intensity provide information about the temperature, and its chemical composition. MCAO systems employ several guide stars allowing a tomographic measurement of the volume of turbulence and attempt to correct it using a number of deformable mirrors [DM] conjugated at different altitude layers. This technique permits to extend the corrected field of view and, at the same time, from the point of view of spectroscopy, would allow to perform extended objects spectroscopy or to provide a quasi uniform encircled energy on the whole field of view of an integral field of view spectrograph unit.

After the current generation of 8–10 m class telescopes, there are plans to built the new generation of ground based telescopes with diameters that range from 30 to 100 m. Moreover, these systems will be provided with multi-conjugated adaptive optics systems in order to overcome the limitations of the classical adaptive optics in terms of anisoplanatism. In the classical adaptive optics systems the problem of sky coverage posed by the use

Further author information: (Send correspondence to D. Bello or R. Conan.)
D. Bello : E-mail: Dolores.Bello@onera.fr
R. Conan : E-mail: rconan@eso.org

of NGSs has been overcome employing artificially created laser guide stars [LGS]. This is the case also of the proposed MCAO system for the Gemini telescope (Rigaut, 2001) which will employ an asterism of 5 LGSs. The necessity of employing LGS for the MCAO systems for the ELTs is still an open question as the sky coverage for these systems should be larger than for classical AOS.

A MCAO demonstrator system has been proposed in the framework of the Research and Training Network on "Adaptive Optics for the Extremely Large Telescopes" funded by the European Comunity. It will be developed for the VLT telescopes as a prototype of the future MCAO systems for the ELTs (Hubin et al., 2001) . This prototype will work with NGSs. Marchetti et al. (2001) have selected stars in the USNO A2 catalogue to get asterisms of three stars with adequate geometry and magnitude for MCAO purpose. Some of these asterisms contain, within the field of view, interesting objects from an astronomical point of view. We have selected two of these objects to provide an example of the performances that such a system could achieve both in H and K bands. The performances are given in terms of Strehl ratio, full width at half maximum, and diameter that encircles the 50% of the energy [EE]. The performances of a classical AOS using one star among those in the field is given also for comparaison.

2. MCAO PRINCIPLE AND SIMULATIONS

The turbulence profile at Cerro Pachon was adopted as C_n^2 profile. It has been modeled with 7 turbulent layers and an outer scale of 25 m. The phase screens on each layer were generated from the theoretical Komogorov power spectral power density by the Fast Fourier Transform method. The diameter is 8 m and the overall D/r_0 is 9 in the K band, corresponding to 0.7 arcsec seeing. The phase measurements are made on 3 NGSs surrounding the object of interest (Figure 1 (b) and Figure 5 (b)) The noise on these measurements corresponds to that of a 9x9 sub-aperture Shack-Hartmann wavefront sensor (one per star) with a 250 Hz sampling frequency and a $3e^-$ read–out noise detector with a quantum efficiency of 50%, leading to various signal to noise ratio depending on the guide star magnitudes.

Two DMs conjugated at 0 and 10 km are employed. The phase is reconstructed on each DM using a 66 Zernike polynomials decomposition. Temporal issues are not modeled, hence each frame corresponds to an open loop measurement, and the final results are obtained with the average of one hundred frames.

The phase on the deformable mirror is reconstructed optimally. This means that we minimize the mean residual variance in the FOV of interest, obtaining the best image quality in the field of view. The reconstructor in this case is made of two different parts: one gives the reconstruction of the turbulent volume over each of the turbulent layers, and the other projects this solution onto the space of modes of the deformable mirrors employed to correct the turbulence volume (see (Conan et al., 2001) for details).

Two different codes were employed to do the simulations. One of them has been developed by T. Fusco -ref???. It is a Monte Carlo simulation modeling the guide stars geometry, the Shack-Hartmann measurements, the turbulent profile and the corrections applied by the deformable mirrors. The other one has been developed by A. Tokovinin, M. Le Louarn and E. Viard (Tokovinin et al., 2001). These two codes are based on the same phase reconstruction method and they were previously cross–checked to verify the good agreement between both.

The first code was employed to simulate the performances obtained over the first object: NGC3366, while the other code was employed for the second object: NGC2346.

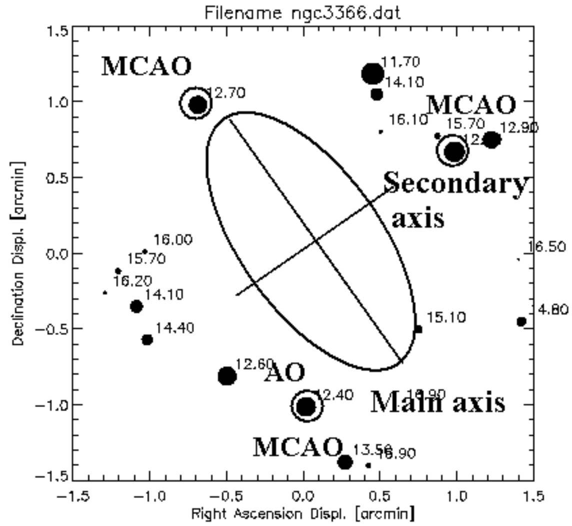
λ	λ/D [mas]
1.65μm (H)	42.54
2.20μm (K)	56.72

Table 1. λ/D values for H and K bands.

3. NGC3366 SIMULATION

Figure 1 (a) shows the image of NGC3366, a spiral galaxy in the southern hemisphere, taken from the Digital Sky Survey (DSS2 red band) of ESO/ST-ECF archive. Figure 1 (b) shows the field of stars surrounding the object and the asterism of NGS (labeled MCAO)) we have selected to test the performances of the system over the real object. One of these stars (labeled AO) is selected also for comparaison of the performances with those

(a) Photograph of the galaxy NGC3366.



(b) Stars surrounding the galaxy NGC3366. The position of the galaxy is shown with the ellipse.

Figure 1.

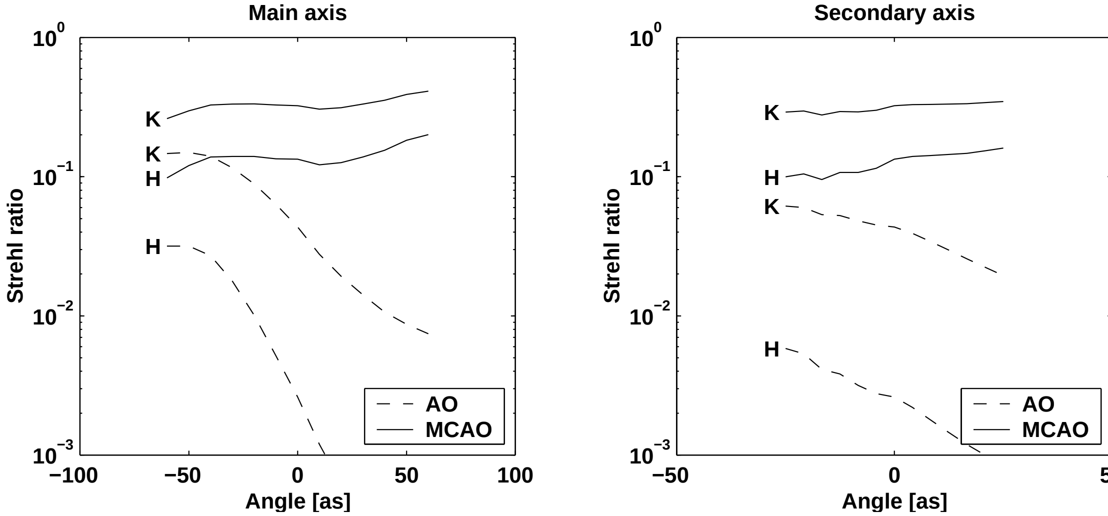


Figure 2. Strehl ratio for the main and the secondary axis of NGC3366. Dashed lines show AO performances and full line MCAO results.

of a classical adaptive optics system. The star magnitudes are 12.70, 12.20, and 12.40. The different parameters will be given along the main and secondary axis, from the bottom to the top for the main axis and from left to right for the secondary axis. The size of the main axis is 120 arcsec, while the secondary axis is 50 arcsec long.

Figure 2 shows the Strehl ratio of the MCAO system (continuous line) and the AO system (dashed line) in both H and K bands and on the main and secondary axis of the galaxy respectively. The Strehl ratio varies between 20% and 30% in K band and between 10% and 20% in H band for MCAO. In AO the Strehl ratio varies from 13% to 0.8% in K band and from 3% to 0.05% in H band.

When interested on spectroscopy it is however more adequate to give the performances of the system in terms of point spread function [PSF] charateristics with the FWHM or with the diameter that encircles a

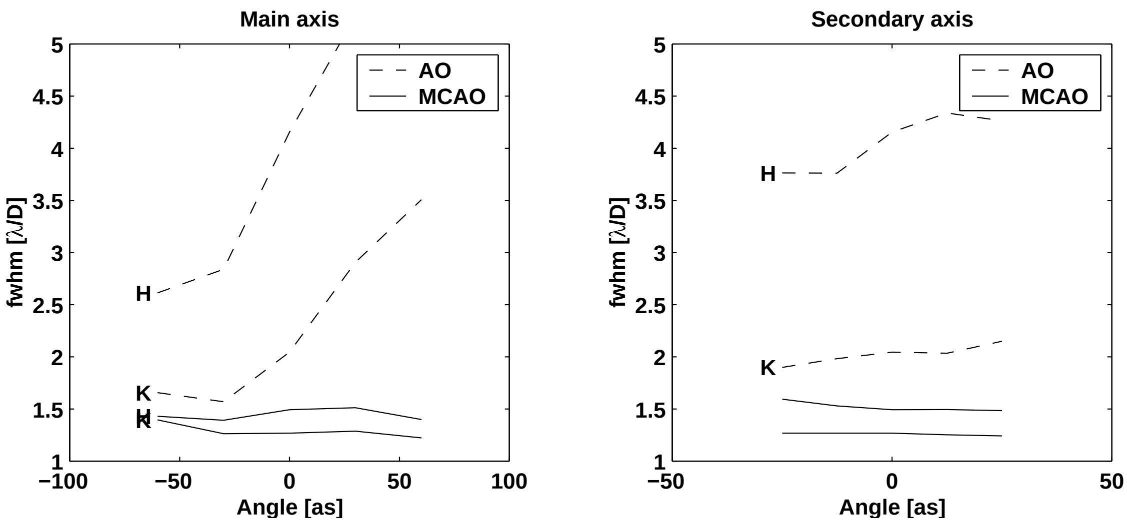


Figure 3. Azimuthal average of the full width half maximum for the main and the secondary axis of NGC3366 in units of λ/D. Dashed lines show AO performances and full line MCAO results.

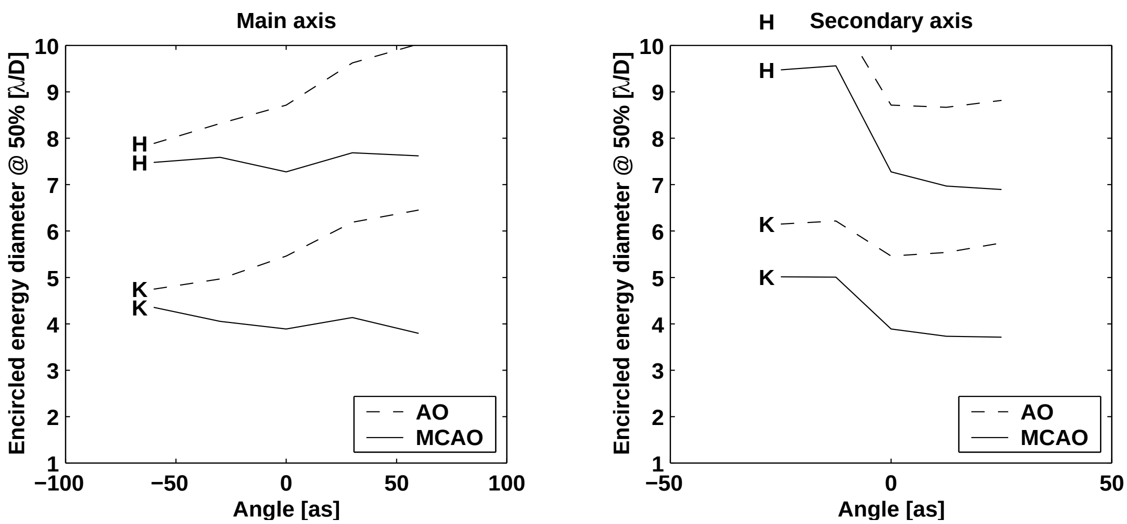


Figure 4. Encircled energy for the main and the secondary axis of NGC3366 in units of λ/D. Dashed lines show AO performances and full line MCAO results.

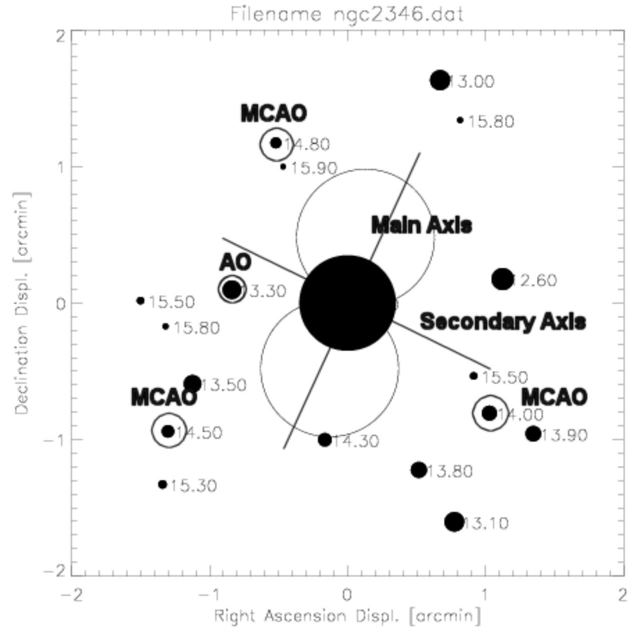
certain amount of the energy. We have chosen the 50% of the energy in this case. The results are shown in figure 3 and figure 4, in units of λ/D. The corresponding values of λ/D for the H and K band are given in table 1. Continuous line correponds to the MCAO case while dashed line corresponds to the classical AO case. The difference between the two case is important for the two bands, but more significant for the H band, where the PSF core quickly spreads out when we move away from the GS.

4. NGC2346 SIMULATION

The planetary nebula NGC2346 (Fig. 1 (a)) has been chosen due to the number of NGSs (Fig. 1 (b)) in its neighborhood with the adequate magnitude, distance to and position around the scientific target.

The simulation is performed in order to obtain the best and the most uniform performances on the two axis drawn in Fig. 1 (b). The different parameters will be given along this two axis browsing them for the top to the bottom for the main axis and from the right to the left for the secondary axis. The performances are compared with the expected ones from an AO system using the NGS labeled AO on Fig. 1 (b). The asterism formed with the three NGSs labeled MCAO provides the reference stars for the MCAO simulation.

(a) Photograph of the nebula NGC2346.



(b) Stars surrounding the nebula NGC2346. The position of the nebula is drawn in the center of the figure. The NGSs for AO and MCAO are surrounded with a circle. The two axis on which the performances of the MCAO system are optimized are also drawn.

Figure 5.

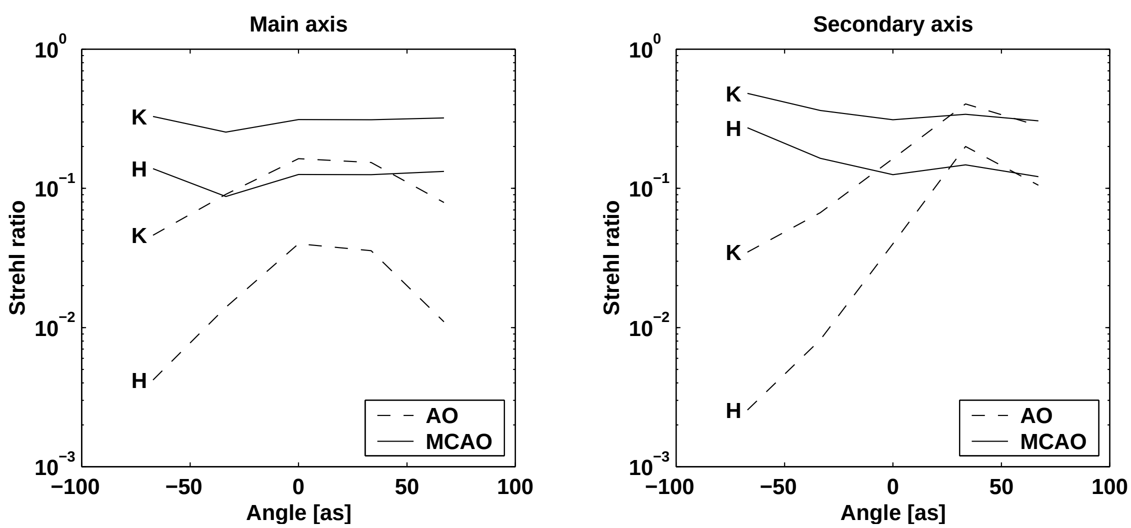


Figure 6. Strehl ratio for the main and the secondary axis of NGC2346. Dashed lines show AO performances and full line MCAO results.

In the figures 6, 7 and 8, dashed lines and full lines correspond to the results of AO and MCAO simulations, respectively. The labels H and K are related to results computed for H and K band respectively. The FWHM and EE are given in units of λ/D.

The Strehl ratio varies from 20% to 50% in K band and from 10% to 30% in H band for MCAO. For AO, it varies from 3% to 50% in K band and from 0.2% to 30% in H band. The highest SR in AO is obtained only closes to GS i.e. closed to the left part of the secondary axis.

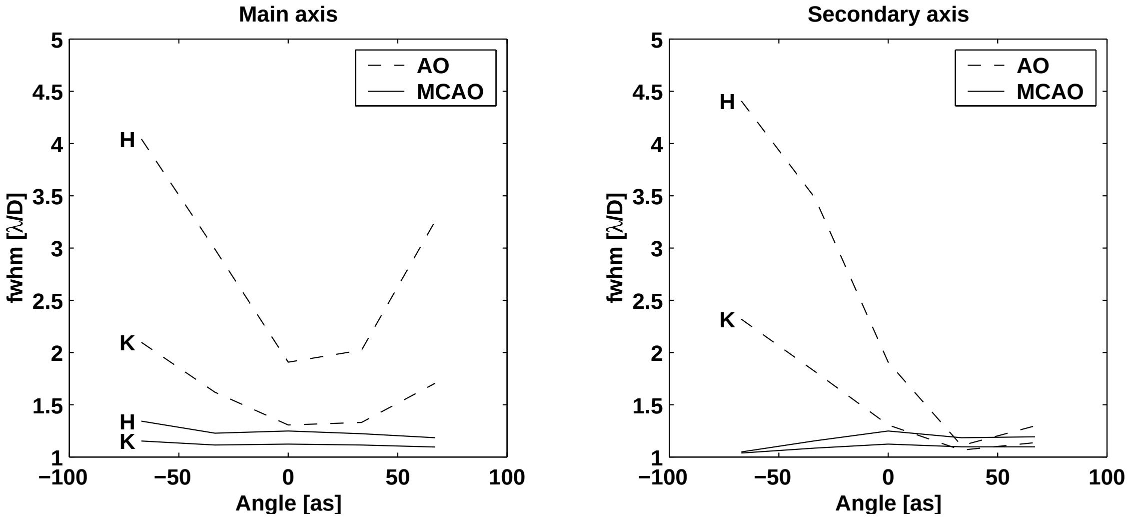


Figure 7. Azimuthal average of the full width half maximum for the main and the secondary axis of NGC2346 in units of λ/D. Dashed lines show AO performances and full line MCAO results.

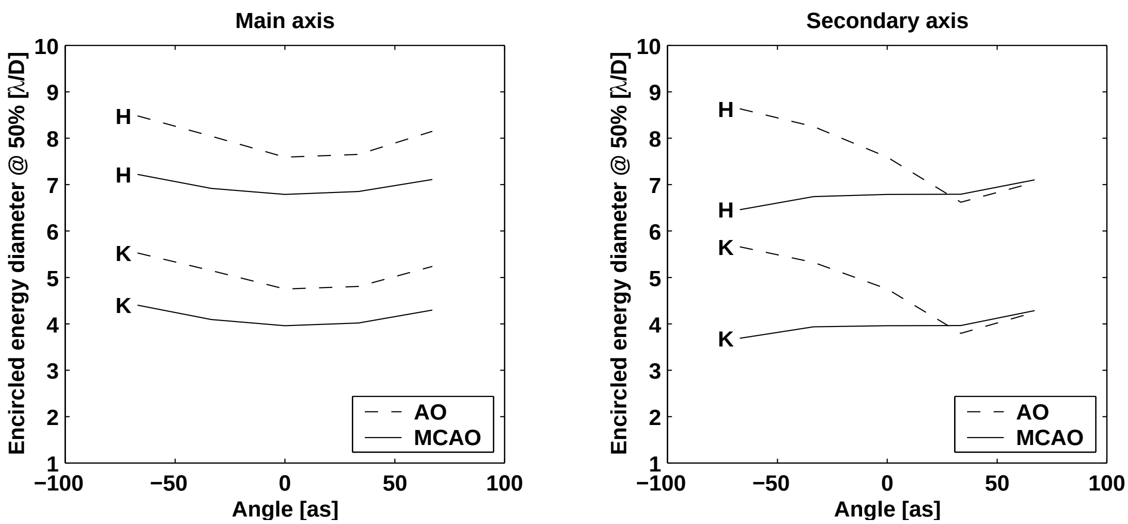


Figure 8. Encircled energy for the main and the secondary axis of NGC2346 in units of λ/D. Dashed lines show AO performances and full line MCAO results.

Figure 7 shows that for MCAO the images resolution is closed to this of diffraction limited images. This is far to be the case for AO in most of the field.

For a point source image, the diameter value that encircles 50% of the energy is closed to λ/D. For MCAO, the EE is 4 to 5 times larger in K band and 6 to 7 times larger in H band. This means that even if we have a PSF core closed to the one given by the diffraction limit, there is still a large halo. For AO, the energy is much more diluted due to the presence of larger halo and core.

5. CONCLUSION

Several authors had previoulsly performed simulations with a regular configuration of guide stars (with a variable number from 3 to 6...). These regular geometrical configurations were able to assure a uniformity of the performances over the field of view. When using NGS, irregular configurations have to be employed with varying stars magnitudes. We have picked up two examples and showed that MCAO techniques are still able to provide uniform performances over the field of view with non regular stars configurations. Moreover we have also plotted the results that could be expected for these objects employing classical AO, with one of the stars of the field. The results are quickly degraded when moving away from the reference. The uniformity of the performance obtained with MCAO can not be achieved with AO even if we change the guide star for a more suitable one for each portion of the object, due to the limited size of the anisoplanatic angle.

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