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CANARY: A PATHFINDER OF MOAO FOR ELT

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Abstract. MOAO is a wide field adaptive optics system which has been firstly developed to reach the requirements involved for the analysis of the formation and evolution of the high-redshift galaxies. The Canary project was birth from the Eagle project - the first multi-object spectrograph in the near infra-red proposed for the European-Extremely Large Telescope (E-ELT) - as a technical demonstrator of the MOAO. The role of Canary is to demonstrate on-sky the feasibility and reliability of the MOAO and to quantify the nominal performance of MOAO. On-sky results , obtained in 2012 and 2013, are presented in this paper.

Keywords: Adaptive Optics - MOAO - Tomography - Laser Guide Stars - ELT - Canary

1 Introduction

One of the future great challenge in Infra-red astronomy concerns the study of the formation and evolution of the first galaxies of the Universe. Thanks to the collecting power of the Extremely Large Telescopes (Cuby, J.-G. 2010), it will be feasible to deeply analyze by spectroscopy high redshift galaxies ($z \sim 7$). Nevertheless, such an analysis requires an on-sky multiplex observation of more than ten very faint galaxies distributed on a very large field of view of the ELT. Some scientific projects, as EAGLE and EVE (Evans,C.-J. et al. 2012), could involve a few ten of milliarcsec resolution that can be only reached with an large field of view Adaptive Optics system based on Laser Guide Stars to compensate the lack of natural guide stars in such cosmological fields.

Multi-object Adaptive Optics has been revealed as the most adapted adaptive optics system to reach these requirements. However,the feasibility and performance of MOAO has to be demonstrated on-sky, especially the open-loop configuration, the tomographic reconstruction and the instrumental calibrations must be validated on-sky. That is the role of Canary (Myers, R. M. et al. 2008) - the technical demonstrator of MOAO - which is set at the William Hershel Telescope. A first on-sky demonstration of the MOAO using only NGS has already been lead in 2010 (Gendron,E. et al. 2011). We gives in this proceedings an overview of the on-sky results of Canary using both Rayleigh LGS and NGS obtained more recently.

2 The Canary experiment

The Canary project has been started from 2007 and the observation runs take place at the William Hershel Telescope at La Palma. The demonstration of the feasibility of the MOAO using LGS in an EAGLE configuration on a E-ELT has been split into three phases. The first one (phase A) has concerned the on-sky validation of the MOAO using only three NGS and has been successfully passed in 2010 (Gendron,E. et al. 2011). We will present the results of the phase B successfully passed in 2012, using one LGS, and in 2013 using four LGS. Finally, during the phase C, Canary will be design as a single scientific channel MOAO system to simulate EAGLE on a ELT, with a first closed-loop stage to compensate the ground layer and a second stage of pure MOAO.

In order to quantify the on-sky performance of Canary, we are using both a diagnostic Shack-Hartmann sensor - the Truth Sensor (TS) - which is looking at the DM, and an IR camera which delivers PSFs on J (1,28 μm), H (1,67 μm) and K (2,2 μm) band. Thanks to the TS, we are able to close the loop in SCAO and

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compare with the performance of MOAO. We compare with GLAO as well in order to quantify the impact of the tomographic reconstruction in the global performance.

This tomographic reconstruction is performed thanks to the Learn&Apply algorithm (Vidal,F. et al. 2010) based on a Minimum Mean Square Error (MMSE) reconstruction of the TS slopes. This algorithm is split into two steps: the first one is an identification step of the turbulent profile and some calibration parameters. Then, thanks to this identification and a model of the spatial covariance of the turbulence, we are able to compute the MMSE reconstructor to be applied on the off-axis measurements (Martin,O. et al. 2012).

3 On-sky results with LGS

3.1 Phase B1 results

In 2012, We have demonstrated the validity of the MOAO using three NGS and one LGS focused at 13.5 km. We were particularly dominated by a slow ground layer - with an average seeing of 0.7" and an average wind speed of 4 m/s to be compared to respectively 0.25" and 8 m/s for the altitude turbulence. From all the measurements we have got during the phase B1 observation runs, we have computed the histograms of the seeing and wind speeds which have been reported in Fig. 1. From such results, we can conclude that MOAO and GLAO will give close tomographic results since the altitude layers are very weak compared to the ground layer.

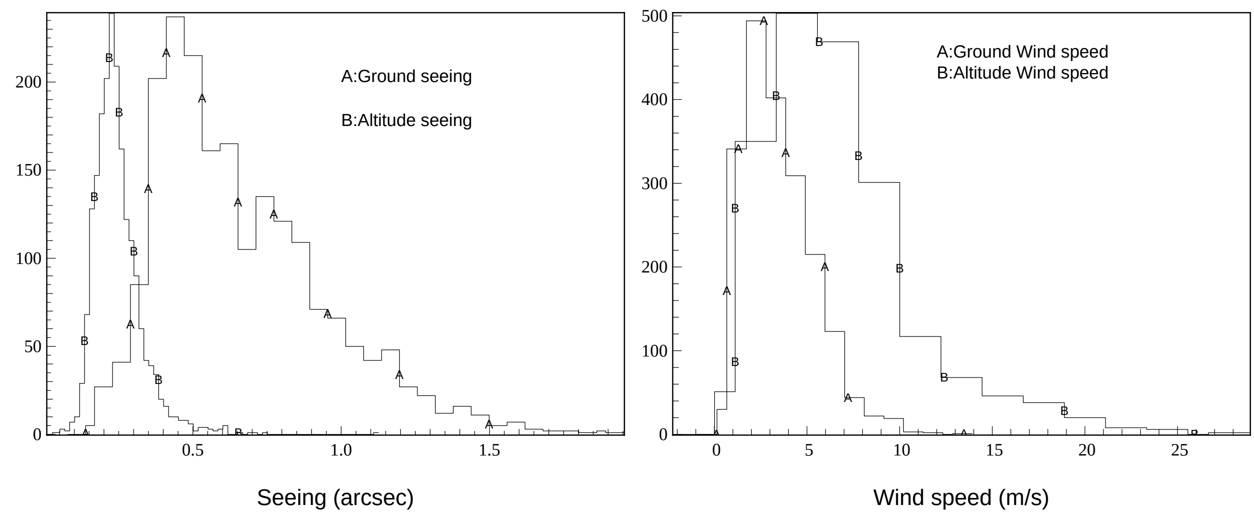

Fig. 1. Left: Histograms of the ground seeing and altitude seeings computed from all the data sets of Canary acquired in 2012.**Right:** Histograms of the ground and altitude wind speed computed from all the data sets of Canary acquired in 2012.

Nevertheless, in Fig. 2, we illustrate that the tomographic reconstruction brings a significant improvements to the global performance measured by the Strehl ratio. In this figure, we note three trends of behaviour on the Strehl ratio as function of the r_0. Despite the scattering of the curves (especially for MOAO and GLAO) due to the variation of the observation conditions - in particular the distribution of the turbulent energy in altitude and the wind speed profile - MOAO looks pretty close to SCAO performance and better than GLAO performance although we were dominated by the ground seeing.

We have also reported in Fig. 2 the tomographic error computed from the difference between the TS slopes in open-loop and the tomographic reconstruction (Martin,O. et al. 2012) that gives a first indication on the tomographic performance of our reconstruction. Finally, we can note that MOAO and GLAO gives very similar results when the r_0 is particularly low, in others words, when the ground layer is strongly turbulent. The constancy of the altitude seeing could be an input for simulation in AO and the ground seeing should be rescaled with respect to the global seeing.

3.2 Phase B2 results

We describe here the results we have got in 2013 on the feasibility of MOAO using 3 NGS and 4 LGS focused at 21 km. In Fig. 3, we have reported the Strehl ratios and the tomographic errors as function of the r_0. Not

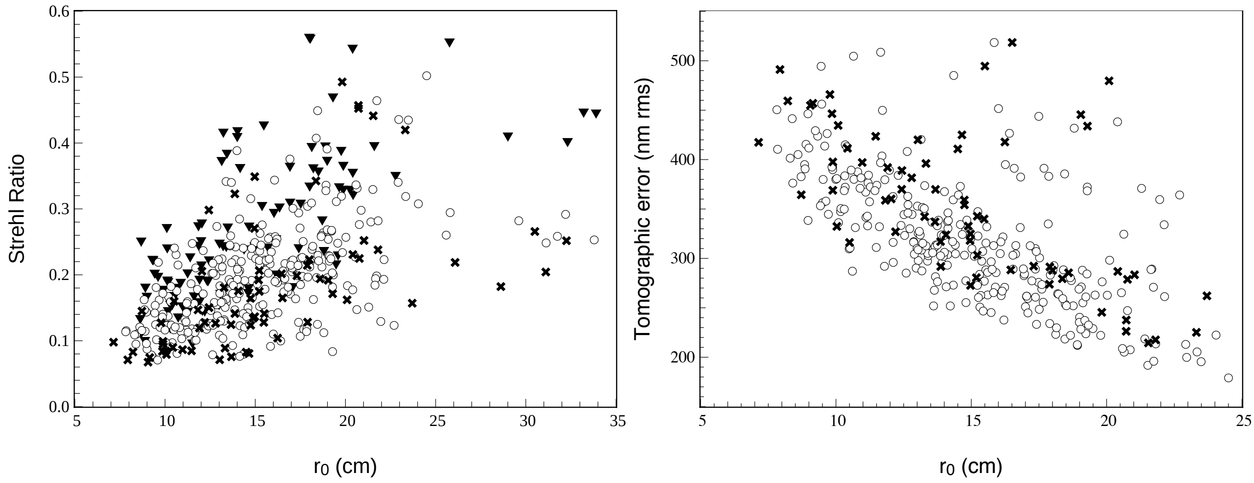

Fig. 2. Left: Strehl ratios measured on-sky in SCAO (triangles), MOAO (circles) and GLAO (crosses) as function of the r_0. **Right:** Tomographic error in MOAO (circles) and GLAO (crosses) as function of the r_0. These results have been acquired by Canary in 2012 using three NGS and one LGS.

surprisingly, we get back the same trends as in 2012, nevertheless MOAO is closer to the SCAO compared to 2012 - especially thanks a greater number of LGS but also thanks to a higher focusing altitude of the LGS with a comparable SNR. We have reported in Fig. 4 IR images of the same target acquired by Canary in 2013 in

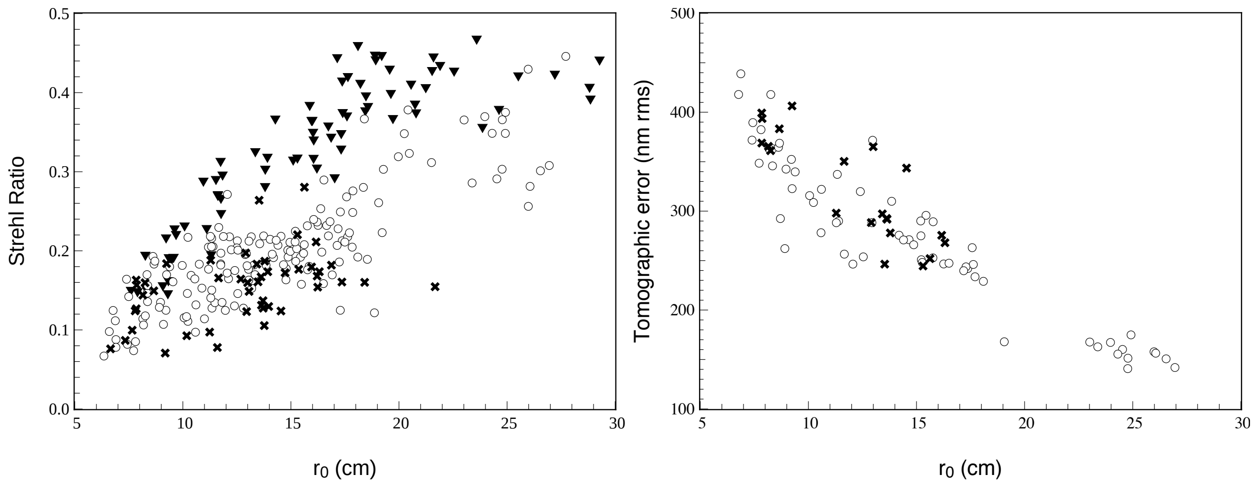

Fig. 3. Left: Strehl ratios measured on-sky in SCAO (triangles), MOAO (circles) and GLAO (crosses) as function of the r_0. **Right:** Tomographic error in MOAO (circles) and GLAO (crosses) as function of the r_0. These results have been acquired by Canary in 2013 using three NGS and four LGS.

open-loop, SCAO, MOAO and GLAO using two NGS and four LGS. These images are an average of thirty one second exposure image and all of them was acquired with very comparable observation condition. When we are running the AO system, we are able to resolve the companion of the binary and the most important is to notice that the MOAO allows to reach a very comparable resolution power than the SCAO and much better than the GLAO.

4 Conclusions

MOAO is a wide field adaptive optics technique which has been developed in order to reach the requirements of a multi-object integral field spectrograph on ELTs. In order to demonstrate the feasibility of MOAO on-sky, the technical demonstrator Canary has been set at the William Hershel Telescope at La Palma. Since 2010,

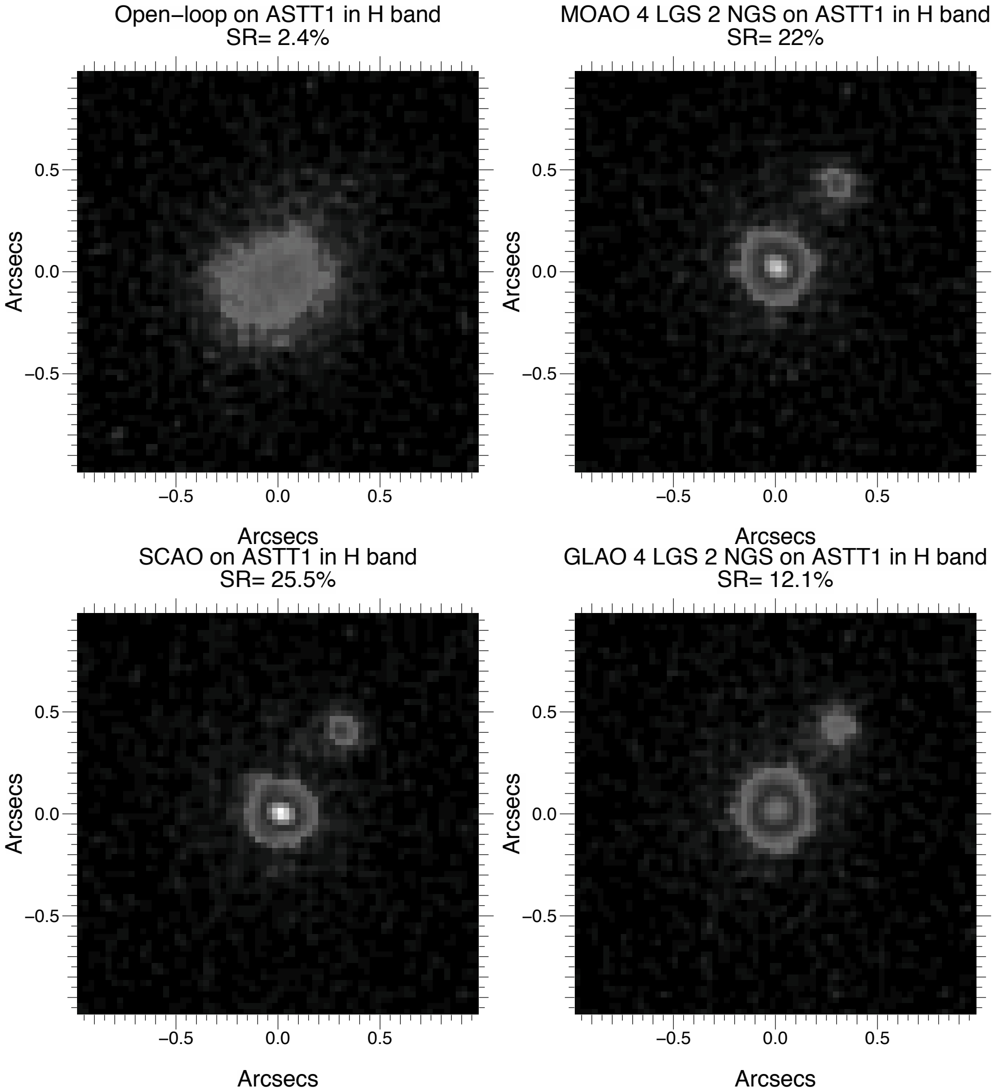

Fig. 4. Psfs in Open-loop - MOAO - SCAO and GLAO on the same object (a binary) and with similar observation conditions acquired in 2013.

we have demonstrated the capability of MOAO using both NGS and Rayleigh LGS and the performance of the mixed NGS/LGS tomographic reconstruction using the Learn&Apply algorithm. MOAO is mandatory for multi-objects spectroscopy on faint galaxies on ELTs and the future results of Canary will give a determinant information for the implementation of MOAO on a ELT.

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