



**HAL**  
open science

## Phase A study of the GNAO bench

Pierre Jouve, Thierry Fusco, Carlos Correia, Benoit Neichel, Cedric Taissir Heritier, Jean-François Sauvage, Jon Lawrence, Andrew Rakich, Jessica Zheng, Timothy Chin, et al.

► **To cite this version:**

Pierre Jouve, Thierry Fusco, Carlos Correia, Benoit Neichel, Cedric Taissir Heritier, et al.. Phase A study of the GNAO bench. Adaptive Optics for Extremely Large Telescopes 7th Edition, ONERA, Jun 2023, Avignon, France. 10.13009/AO4ELT7-2023-104 . hal-04419885

**HAL Id: hal-04419885**

**<https://hal.science/hal-04419885v1>**

Submitted on 26 Jan 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



## Phase A study of the GNAO bench.

Pierre Jouve<sup>a</sup>, Thierry Fusco<sup>a,b,c</sup>, Carlos Correia<sup>g</sup>, Benoit Neichel<sup>c</sup>, Taïssir Heritier<sup>a,c</sup>, Jean-François Sauvage<sup>a,c</sup>, Jon Lawrence<sup>f</sup>, Andrew Rakich<sup>e</sup>, Jessica Zheng<sup>f</sup>, Timothy Chin<sup>f</sup>, Nicolas Vedrene<sup>b</sup>, Julien Charton<sup>d</sup>, and Piero Bruno<sup>d</sup>

<sup>a</sup>DOTA, ONERA, F-13661 Salon cedex Air - France

<sup>b</sup>DOTA, ONERA, Université Paris Saclay, F-91123 Palaiseau - France

<sup>c</sup>LAM-Laboratoire d'Astrophysique de Marseille, UMR 7326, 13388, Marseille, France

<sup>d</sup>ALPAO, 727 Rue Aristide Berges, 38330 Montbonnot-Saint-Martin

<sup>e</sup>Mersenne Optical Consulting, Raumati Beach, NZ

<sup>f</sup>Australian Astronomical Optics - Macquarie, Macquarie University, Sydney, NSW, 2109, Australia

<sup>g</sup>Space ODT - Porto, Portugal

### ABSTRACT

AOB-1 is an Adaptive Optics (AO) facility currently designed to feed the Gemini infrared Multi Object Spectrograph (GIRMOS) on the GEMINI North 8m class telescope located in Hawaii. This AO system will be made of two AO modes. A laser tomography AO (LTAO) mode using 4 LGS (laser guide stars) and [1-3] NGS (natural guide stars) for high performance over a narrow field of view (a few arcsec). The LTAO reconstruction will benefit from the most recent developments in the field, such as the super-resolution concept for the multi-LGS tomographic system, the calibration and optimization of the system on the sky, etc. The system will also operate in Ground Layer Adaptive Optics (GLAO) mode providing a robust solution for homogeneous partial AO correction over a wide 2' FOV. This last mode will also be used as a first step of a MOAO (Multi-object adaptive optics) mode integrated in the GIRMOS instrument. Both GLAO and LTAO modes are optimized to provide the best possible sky coverage, up to 60% at the North Galactic Pole. Finally, the project has been designed from day one as a fast-track, cost effective project, aiming to provide a first scientific light on the telescope by 2027 at the latest, with a good balance of innovative and creative concepts combined with standard and well controlled components and solutions. In this paper, we will present the innovative Phase A concepts, design and performance analysis of the two AO modes (LTAO and GLAO) of the AOB-1 project.

**Keywords:** LTAO, GLAO, Super Resolution

---

Further author information: (Send correspondence to pierre.jouve@lam.fr)

# 1. INTRODUCTION

AOB-1 is the next generation adaptive optics (AO) bench for GNAO [7]. AOB-1 is led by a consortium of 5 partners - three from France : ONERA, LAM, ALPAO; two from Australia: ASTRALIS (PI institute), AAO. In addition to that, two associate partners are also collaborating; one from New Zealand : Mersenne Optical consulting and one from Portugal: Space ODT.

AOB-1 will be able to provide diffraction limited scales thanks to two AO modes: a LTAO mode for high performance over a field of view (FOV) of  $20'' \times 20''$ , and a GLAO mode providing medium correction over a FOV of  $120'' \times 120''$  as a first step to feed the multi-objet adaptive optics (MOAO) mode of GIRMOS [6]. GIRMOS science will cover Kinematics, star-formation, and stellar populations of galaxies at  $0.7 < z < 2.7$  (Epoch of most active star formation in galaxies), and we summarize the GIRMOS situation regarding other instruments in figure 1.

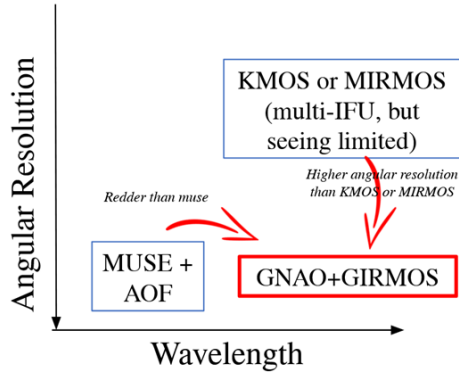


Figure 1: GIRMOS context

# 2. SYSTEM ARCHITECTURE.

AOB-1 is an AO bench designed to provide high performance for 2 AO modes, LTAO and GLAO. The light passing through AOB-1 will undergo a second stage of MOAO correction in the GLAO mode before arriving to the arms of the IFUs (Integral Field Spectrometer). In the LTAO mode, the light will directly go to the IFUs. In figure 2, we present the architecture of AOB-1. The input light beam enters on the top left and comes out at the bottom left of the figure. The light goes first through the calibration module that has been inspired from GeMS. Then through a common path ADC (removable), in that configuration the wobbles induced by the ADC can be seen by the WFSs, and therefore can be corrected. The ADC is optimized for the NIR. There's also an option to add ADC on the NGS path when the common path one is removed. After that, the light goes through the tip-tilt DM and the high order  $32 \times 32$  DM compatible with super resolution. The light is then divided in between the science path ( $0.83 - 2.4 \mu m$ ) and the WFSs path ( $0.45 - 0.83 \mu m$ ). For the NGS path (see section 3.3), we choose to split the light in two bands ( $0.45 - 0.58 \mu m$ ) for the slow focus sensor (SFS) which is a  $2 \times 2$  Shack-Hartmann (SH), and the band ( $0.6 - 0.83 \mu m$ ) for the tip-tilt wavefront sensor (TTWFS). The high order WFS (see section 3.3) using the laser guide star (LGS) light stacks the four pupils sampled by  $18 \times 18$  subapertures each on a single OCAM 2K camera ( $240 \times 240$ ). In this paper we focused our analysis on the WFSs part.

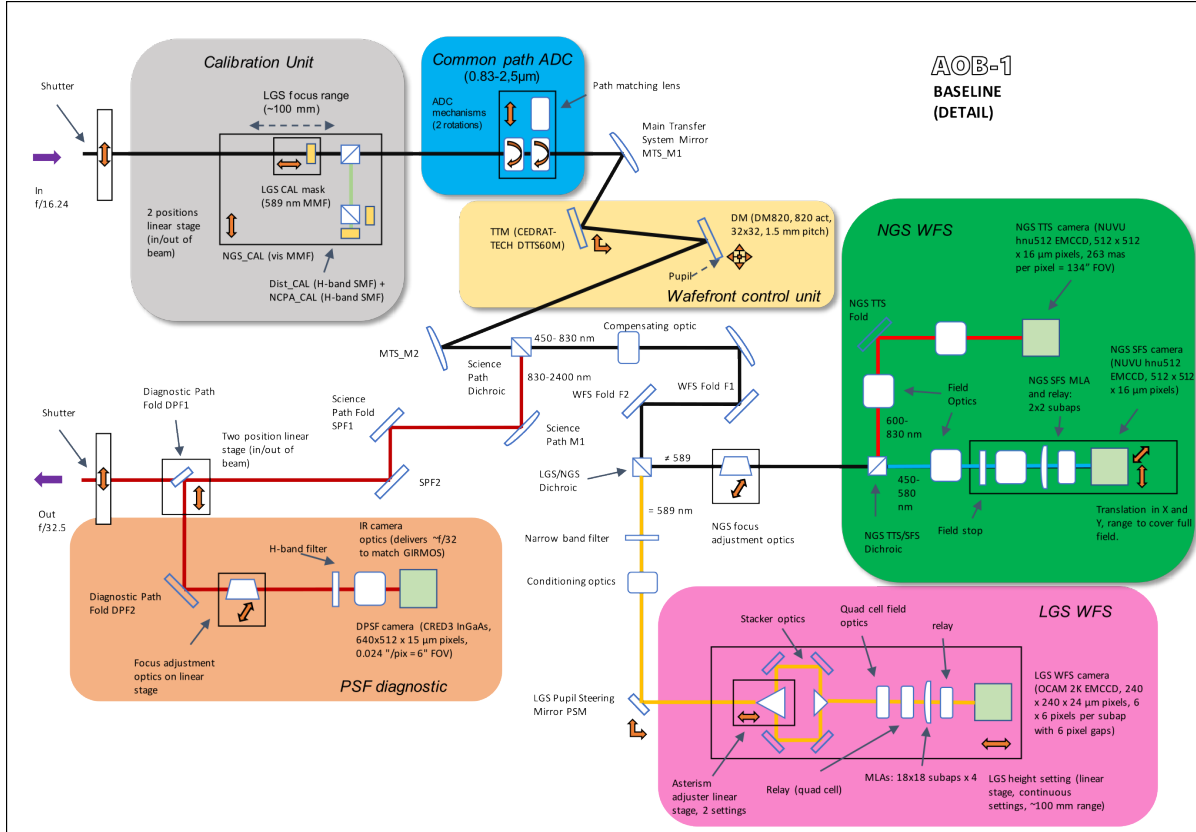


Figure 2: Architecture of AOB-1. Calibration Unit (gray), 2: Common path ADC (blue), Wavefront control unit (yellow), NGSWFS (green), LGSWFS (pink), PSF diagnostic (orange).

### 3. KEY ELEMENTS

In this section, we describe the key elements of the high order wavefront aberration correction that have been investigated in details during the Phase A.

#### 3.1 LGSWFS

The LGSWFS uses the light from the artificial sodium star to measure the high order wavefront aberrations. Our main constraint is the number and power of the LGSs at the Gemini north facility. The facility uses two 20W lasers that are each divided into two beam, giving 4 independent laser of 10W. Using [1] we can obtain a value of the photon return flux  $I_0 = 38.5 \text{ ph/s/cm}^2/\text{W}$ , which is an average value. The photon flux return for a LGS can vary by a factor 6 during the same night [3]. In figure 3, we scan the value of the photon return flux for different type of the detectors (Perfect  $\rightarrow \text{RON} = 0e^-$ , EMCCD  $\rightarrow \text{RON} = 0.5e^-$ , CMOS  $\rightarrow \text{RON} = 3e^-$ ) in the  $J$ -band and  $K$ -band.

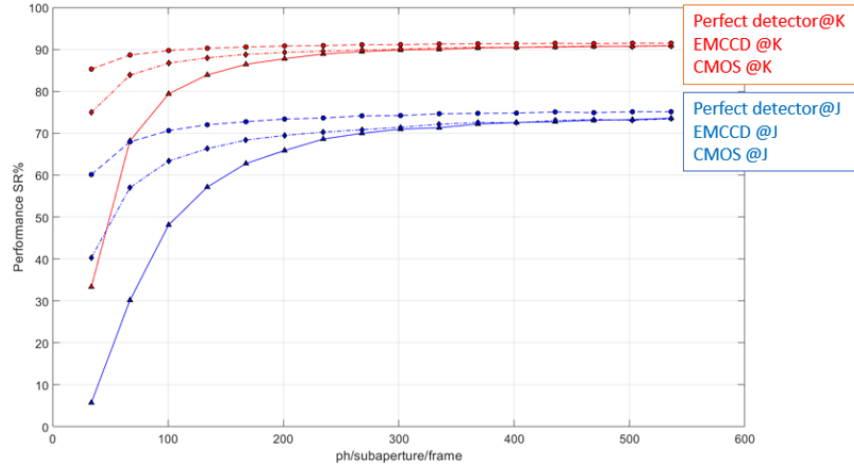


Figure 3: Impact of the detector noise on the performance in  $J$ -band and  $K$ -band for different type of detector.

From 3, the performance for the nominal flux return is not strongly influenced by the type of detector. However, due to the strong variations of the sodium return flux during the telescope operation type, it is safe to say that a CMOS sensor will have worse performance, the difference between the EMCCD and the CMOS accentuates in the  $J$ -band. Therefore, we chose the EMCCD technology for optimal performance. The drawback is the number of detector pixel which is limited at  $240 \times 240$  pixels. To keep a compact design (see figure 4), we stack the for pupil sampled by  $18 \times 18$  subapertures each on the same detector (see figure 4).

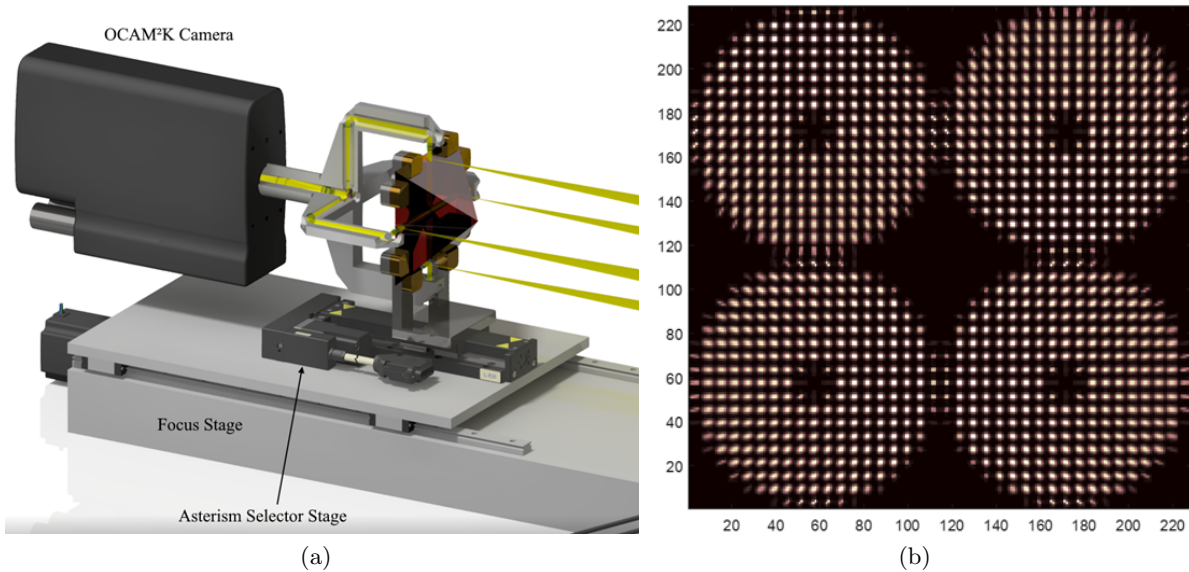


Figure 4: (a): Opto-mechanical design for the LGSWFS. The whole stage can move to adjust the focus, and the pyramid can also move to accommodate the asterism size. (b): We stack the 4 pupil each sample by  $18 \times 18$  subapertures on one detector

Each subaperture contains 6 pixels of 800mas, therefore we can leave some space in between the pupil of the detector to shift the WFSs to be compatible with super-resolution.

### 3.2 Deformable mirror.

The deformable mirror (DM) correcting the high order contribution is a  $32 \times 32$  DM from ALPAO (DM820). This deformable mirror is a component on the shelf (COTS). Also, the  $32 \times 32$  actuators of the DM can be controlled using the information from the four  $18 \times 18$  subapertures SH of the LGSWFS because of the super-resolution concept [2].

### 3.3 NGSWFS

Because of the tip-tilt measurement problem with the LGS [4], we need a natural guide star (NGS) to obtain the low order aberration information. To do so, we use the photons from a NGS in the band  $[0.45 - 0.83] \mu\text{m}$ .

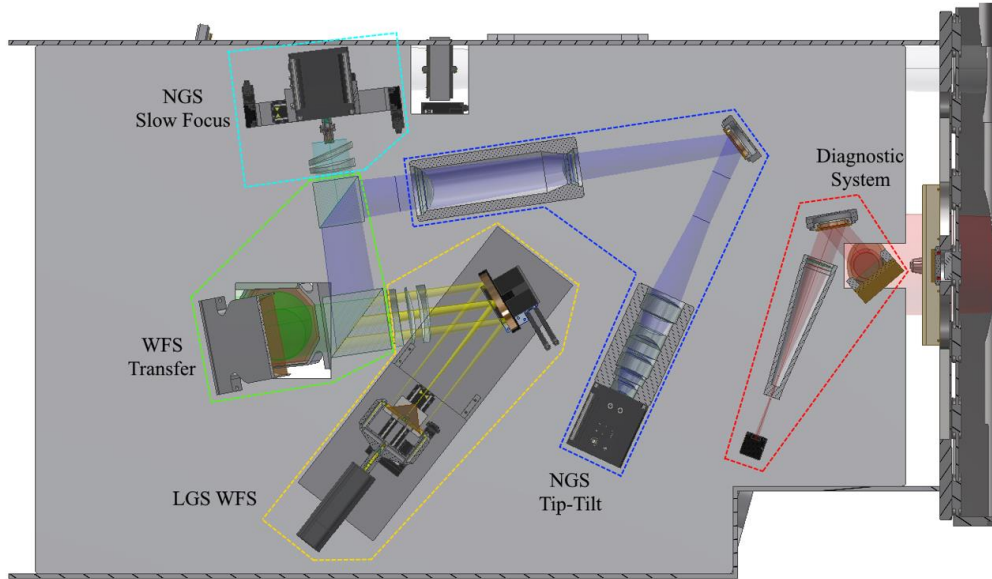


Figure 5: Opto-mechanical design of the WFSs.

We chose to separate the light in two spectral bands, this the system can work with only one NGS, increasing the sky coverage. The slow focus sensor (SFS) uses the  $[0.45 - 0.58] \mu\text{m}$  spectral band, and the  $[0.6 - 0.83] \mu\text{m}$  spectral band is used for the tip-tilt WFS (see figure 5). Indeed, fewer photon are required for the SFS, therefore we use the bluer photons to feed the SFS. The redder photons are used for the TTWFS which run at high framerates (200Hz-1KHz). The SFS is a  $2 \times 2$  SH. The TTWFS is a single lens focusing on a large detector that can accommodate  $2'$  FOV. The tip-tilt stars are selected numerically up to 6 NGSs. This setup has also the advantage to be able to use only one NGS, in figure 6, we show the probability [5] to find one star or two stars in a square of  $1^\circ \times 1^\circ$  at the north galactic pole (NGP) as a function of the fov.

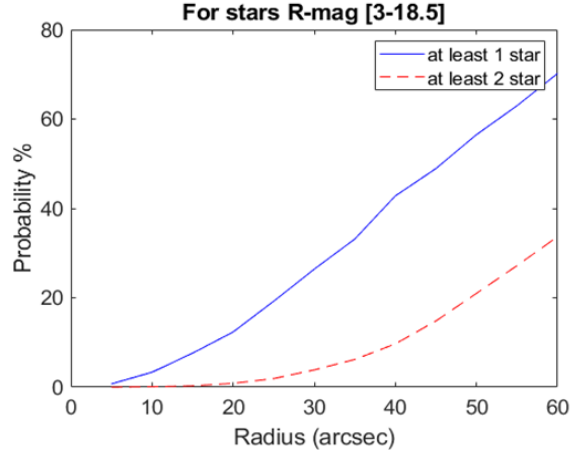


Figure 6: Probability to find one or 2 stars at the NGP in a square of  $1^\circ \times 1^\circ$  as a function of the telescope fov. We consider stars in a range of R-mag [3-18.5]

The figure 6 shows that the probability of finding 1 star within a radius of  $60''$   $P(1 \text{ stars} | r \leq 60'') = 69\%$  and  $P(2 \text{ stars} | r \leq 60'') = 30\%$ .

#### 4. PERFORMANCE ANALYSIS

In this section, we present the performance analysis of the system under typical conditions at Mauna Kea given in the table 1. First the LTAO results given in figure 7, where the 4 LGSs are equally set on a circle of  $8''$ . In this case, we use a central bright NGS to outline the effect of the HO part.

Table 1: Atmospheric conditions used during the simulations.

	Elevation (m)	0	500	1000	2000	4000	8000	16000
	Wind speed(m/s)	5.6	5.77	6.25	7.57	13.31	19.06	12.14
	Wind direction ( $^\circ$ )	190	255	270	350	17	29	66
50%, $r_0=0.186$ m	Turbulence fraction	0.4557	0.1295	0.0442	0.0506	0.117	0.0926	0.1107



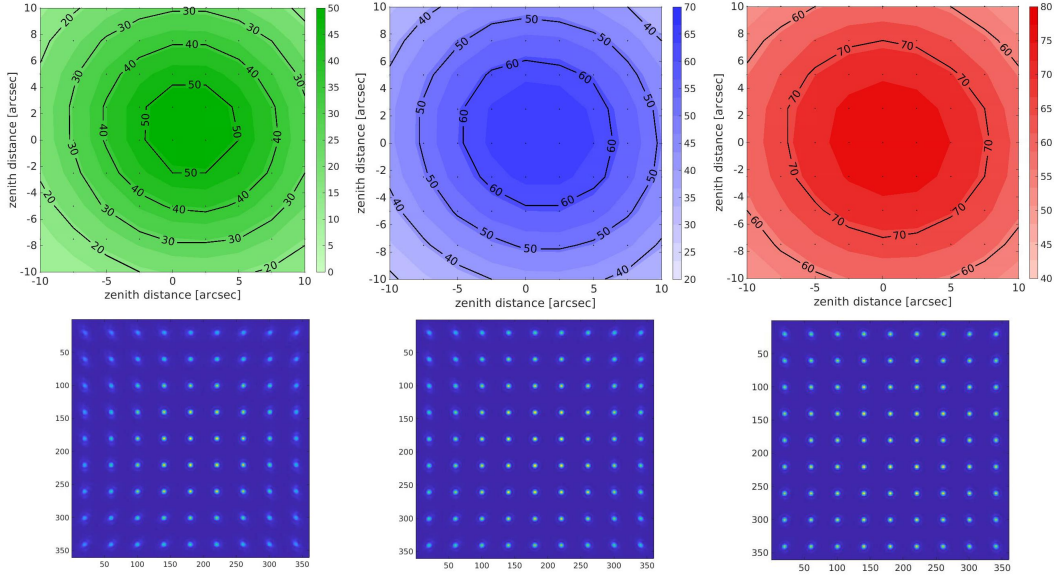


Figure 7: Performance LTAO over a  $20'' \times 20''$  field in  $J$ -band (green),  $H$ -band (blue),  $K$ -band (red).

Table 2: Strehl ratio for the LTAO case.  $ZA = 25^\circ$ ,  $r_0 = 18.6\text{cm}$

	mean SR[%]	max SR[%]	min SR[%]
science $J$ -band	30	53	9
science $H$ -band	50	68	26
science $K$ -band	63	76	44

Table 3: FWHM for the LTAO case.  $ZA = 25^\circ$ ,  $r_0 = 18.6\text{cm}$

	mean FWHM [mas]	max FWHM [mas]	min FWHM [mas]
science $J$ -band	36	44	34
science $H$ -band	46	50	44
science $K$ -band	59	62	58

In figure 8, we give the performance of the GLAO mode in FWHM (mas) for the three science band  $J, H, K$ . In this mode the LGS are on a circle of radius  $58''$ .



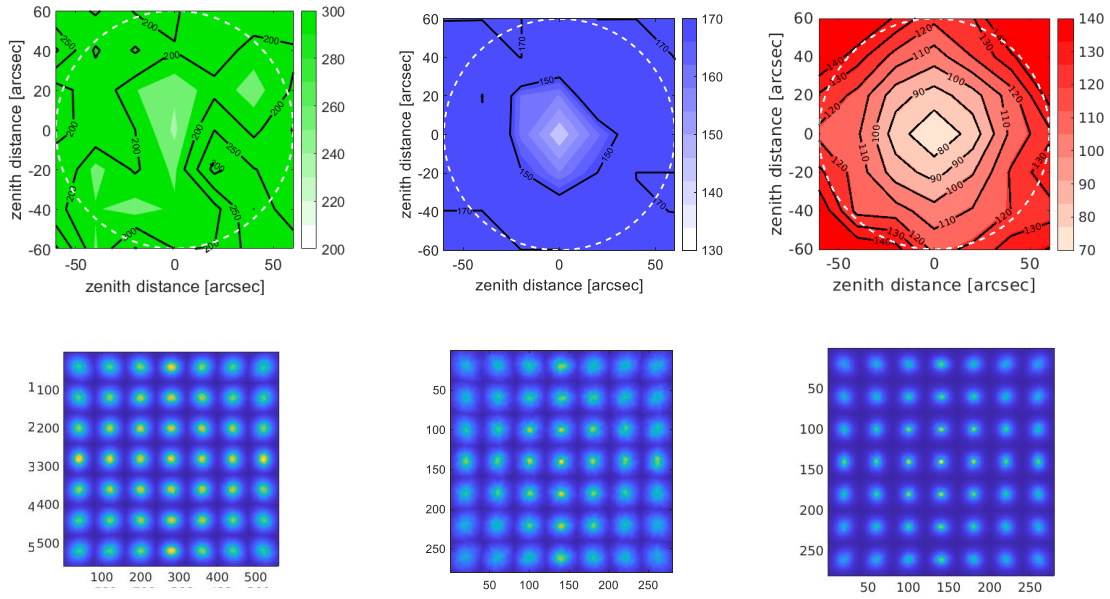


Figure 8: Performance GLAO over a  $60'' \times 60''$  fov in  $J$ -band (green),  $H$ -band(blue),  $K$ -band(red).  $ZA= 50^\circ$ ,  $r_0 = 18.6\text{cm}$

Table 4: FWHM for the GLAO case.  $ZA= 50^\circ$ ,  $r_0 = 18.6\text{cm}$

	mean FWHM [mas]	max FWHM [mas]	min FWHM [mas]
science $J$ -band	$203 \pm 44$	316	133
science $H$ -band	$158 \pm 22$	182	102
science $K$ -band	$114 \pm 16$	145	76

To illustrate the performances, in figure 9 we have simulated a star cluster in a field of  $2' \times 2'$  and interpolated the PSF from the E2E to recreate an image of the cluster.

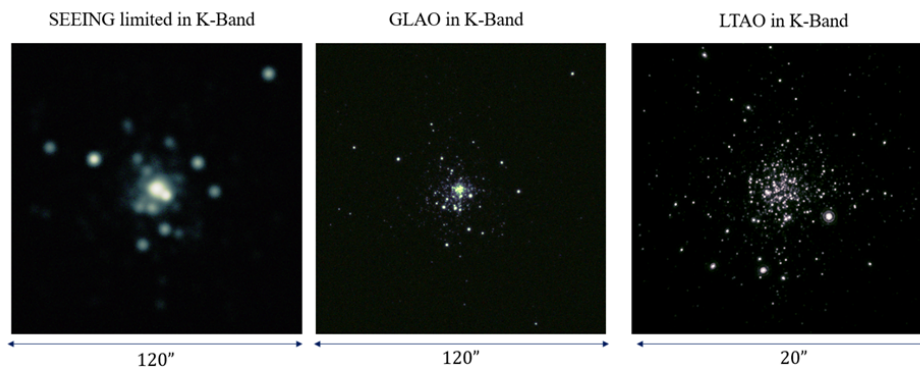


Figure 9: Image of a star cluster in  $K$ -band using the simulated performances of GNAO, left: seeing limited, center: GLAO mode, right: LTAO mode.  $ZA=50^\circ$ ,  $r_0 = 18.6\text{cm}$ .

In figure 9, the GLAO mode only consider the correction of GNAO, not the second stage of MOAO from GIRMOS.

## 5. CONCLUSION AND OUTLOOK

We achieved important steps in the design of AOB-1:

- The light from the LGS will be analyzed by 4 SH of 18x18 subapertures each, the four pupils are stacked on one EMCCD detector of  $240 \times 240$  pixels. The design is compatible with super-resolution and allows us to control a  $32 \times 32$  DM (DM820 ALPAO).
- To maximize the the sky coverage, we split the NGS light in 2 spectral bands in between the TTWFS and the SFS.
- We have simulated the performances in the LTAO mode including super-resolution. We have also simulated the performance in the GLAO mode.

In the end, we proposed a viable, robust and flexible design for GNAO. The AO system exploits the Gemini north facility resources to the fullest and is compatible with a fast-track project. The next steps are to provide a more precise estimate of the sky coverage, and provide a sensitivity analysis.

## ACKNOWLEDGMENTS

### References

- [1] Ronald Holzlöhner et al. “Optimization of cw sodium laser guide star efficiency”. In: *Astronomy & Astrophysics* 510 (2010), A20.
- [2] Sylvain Oberti et al. “Super-resolution wavefront reconstruction”. In: *Astronomy & Astrophysics* 667 (2022), A48.
- [3] T Pfrommer and P Hickson. “High resolution mesospheric sodium properties for adaptive optics applications”. In: *Astronomy & Astrophysics* 565 (2014), A102.
- [4] Francois Rigaut and Eric Gendron. “Laser guide star in adaptive optics-The tilt determination problem”. In: *Astronomy and Astrophysics (ISSN 0004-6361)*, vol. 261, no. 2, p. 677-684. 261 (1992), pp. 677–684.
- [5] Annie C Robin et al. “The Besancon Model of stellar Population synthesis of the Galaxy”. In: *Red Giants as Probes of the Structure and Evolution of the Milky Way*. Springer. 2012, pp. 171–180.
- [6] Suresh Sivanandam et al. “Gemini infrared multi-object spectrograph: instrument overview”. In: *Ground-based and Airborne Instrumentation for Astronomy VII*. Vol. 10702. SPIE. 2018, pp. 456–467.
- [7] Gaetano Sivo et al. “Gemini North Adaptive Optics facility overview and status updates”. In: *Adaptive Optics Systems VIII*. Vol. 12185. SPIE. 2022, p. 1218536.