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Preliminary performance analysis of a LGS system for GTC

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ABSTRACT

The Gran Telescopio Canarias (GTC) Adaptive Optics (AO) system, designed to work with Natural Guide Stars (NGS), is in its laboratory integration phase. The upgrade for the operation with a Laser Guide Star (LGS) has been approved, and the design of the LGS Facility is going to start. Hereafter we analyse the performance of a LGS AO system taking into account the GTC characteristics and error budget. Two scenarios are studied: launching the laser from the centre of the telescope aperture behind the secondary (on axis) and launching from the side of the primary mirror (off axis). The simulations have been performed using the Fractal Iterative Method (FrIM), a fast-reconstruction algorithm, with the parameters of the GTC for the telescope, the atmospheric profiles of the Observatorio del Roque de Los Muchachos (ORM), and data from the laser star unit developed by ESO.

Keywords: adaptive optics, LGS, large telescopes

1. INTRODUCTION

In this paper we analyse the performance of an LGS AO system to be installed at GTC. Two scenarios are chosen: launching the laser from the centre of the aperture and from the side. The simulations have been performed using FrIM, a fast-reconstruction algorithm, using the parameters written in Table 1 and the atmospheric profile from Fuensalida et al.[1] shown on Figure 1.

One constraint of AO with NGS is that very few astronomical targets are suited for this technique: to get the best performance they have to be brighter than V~15 mag (for the GTC in good seeing conditions) and within a field of view of 15-20 arcsec. With a LGS this restriction is much relaxed[2]. One still needs to find a NGS for the tip-tilt correction, but it can be twice fainter than a NGS required for correction. That means that the sky coverage with LGS-AO is much higher than with NGS-AO. But as the sky coverage increases the achievable Strehl decreases due to two effects: the cone effect and the residual tip-tilt jitter.

The cone effect is due to the finite altitude of the artificial star. The LGS emits a spherical wavefront, which does not pass through the same turbulence as a natural star. Nevertheless the scientific target is corrected by use of the phase measurements of the laser light. The induced error is called the cone effect, or focus anisoplanatism. It induces a systemic erroneous correction and thus limits the improvement of the image quality. It becomes more critical towards shorter wavelengths, for larger telescopes and for high altitude seeing[3]. The residual image motion from the NGS tip-tilt star, which may be faint and far off-axis, is called tip-tilt jitter.

Diameter	10 m
Obscuration	6%
Subapertures/diam	20
LGS WFS Pix/subap	10
TTGS WFS Pix/subap	10
Na layer height	90 km
Na layer thickness	10 km
LGS brightness m_{AB}	7.5
TTNGS brightness m_{AB}	13
r_0 @ 550 nm	14 and 20 cm
Seeing @ 550 nm	0.8 and 0.6 arcsec
L_0	25 m
LGS WFS Field stop	4, 5, 7 arcsec
Pixel scale	0.4, 0.5, 0.7 arcsec/pix
Image fwhm	2 pixels
TTGS WFS Field stop	3.5 arcsec
Frequency	500 Hz
Temporal coherence	2 ms
Frames	2
WFS ron	0.1 e/pix/frame
Wavelength	2.2 μm

Table 1: simulation parameters

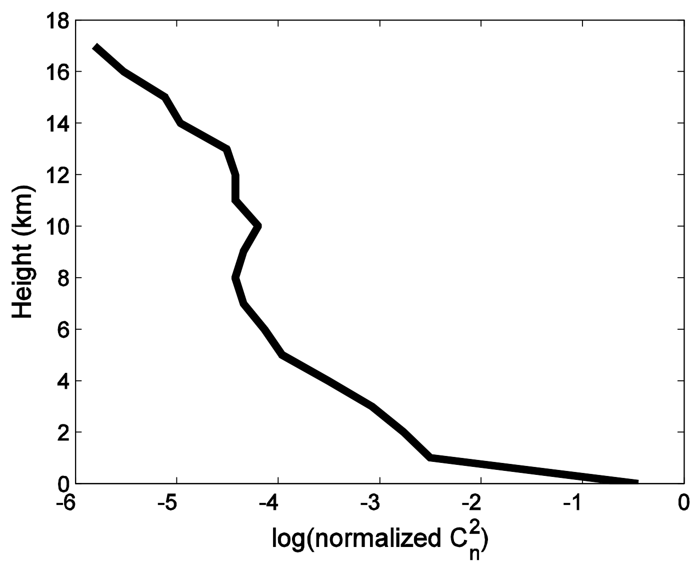


Figure 1: atmospheric profile from Fuensalida[1]

Regarding the parameters of Table 1, most of them are given by the GTC AO baseline. The magnitude of the LGS is taken from Bonaccini[4]. The field stop is chosen in order to satisfy two needs: on one hand, the elongated spot of the laser has to be truncated as minimum as possible, on the other hand, the amount of pixels is limited but the sampling has to be enough to avoid aliasing. In Figure 2 is plotted the elongation of the laser spot for each subaperture. The maximum elongation is 1.4 arcsec when launching from the centre and 2.8 arcsec when launching from the side. We found that a field stop of 5 arcsec was enough not to truncate the spot in case of launching from the centre or from the side, but the sampling was a bit limited for a very good seeing scenario, while a field spot of 4 arcsec was a bit limited for the side launching case, but the sampling was enough for any case. We have performed simulations for 7, 5 and 4 arcsec field stops.

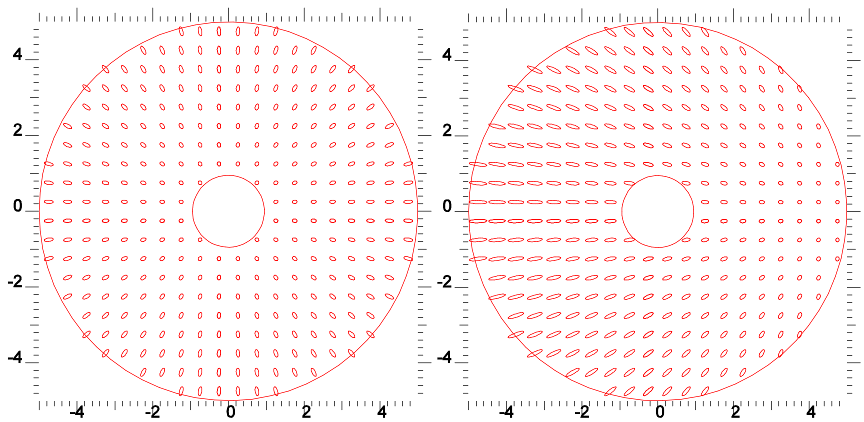


Figure 2: elongation of the laser stop in the subapertures. The right figure shows the elongation when launching from the side of the aperture, and the left figure when launching from the canter.

2. GTCAO ERROR BUDGET

To evaluate the performance of the system we use the rms given by the simulations for the cone effect, tilt-jitter and the fitting error. The temporal delay error or bandwidth error, in case no temporal prediction is made, can be estimated using the following expression, from Parenti and Sasiela[5]:

$$\sigma_{delay}^2 = 0.962\left({}^{\tau}/_{\tau_0}\right)^{5/3}$$

For the rest of the errors, we use the GTCAO error budget (Table 2) for a bright NGS.

Term	Wavefront (nm)
AO system	
Fitting error	119
Bandwidth	54
Calibration NCP	10
Drift NCP	10
DM hysteresis	10
Alignment DM-WFS	40
Calib. spot error	10
Telescope	

Residual	90
Segment vibration	60
Instrument high-f	50
Windshake residual	31.8 nrad
Bandwidth	11.3 nrad

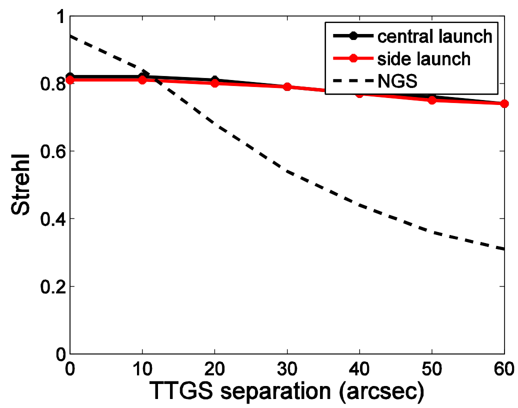
Table 2: GTCAO error budget

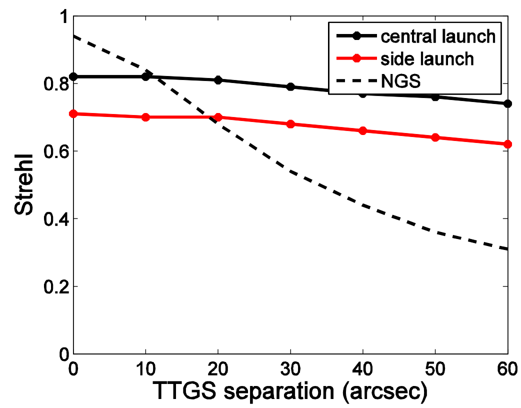
3. RESULTS OF SIMULATIONS

The following figures summarize the expected performance of an LGS facility for the GTCAO.

3.1 Performance as a function of the TTNGS separation

We first compute the results of the simulations with r_0 20 cm. In Figure 3 is plotted the result. In Figure 4 we see the results of the simulations for the more realistic case of having an r_0 14 cm, with a 7, 5 and 4 arcsec field stop. To understand the advantages of using a LGS we have compared the performance with the case of using only a NGS to calculate the correction. We can clearly see how the performance decreases with the separation of the NGS, due to the anisoplanatism. We can see the clear advantage of using an LGS to measure all the modes but the TT and leaving the off-axis NGS to measure the TT mode. The Strehl decreases due to the angular anisokinetism but the effect is much smaller.





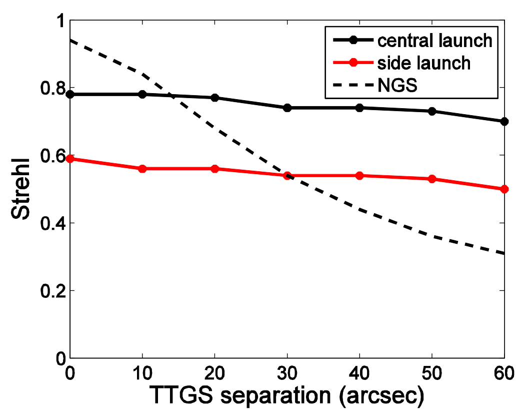
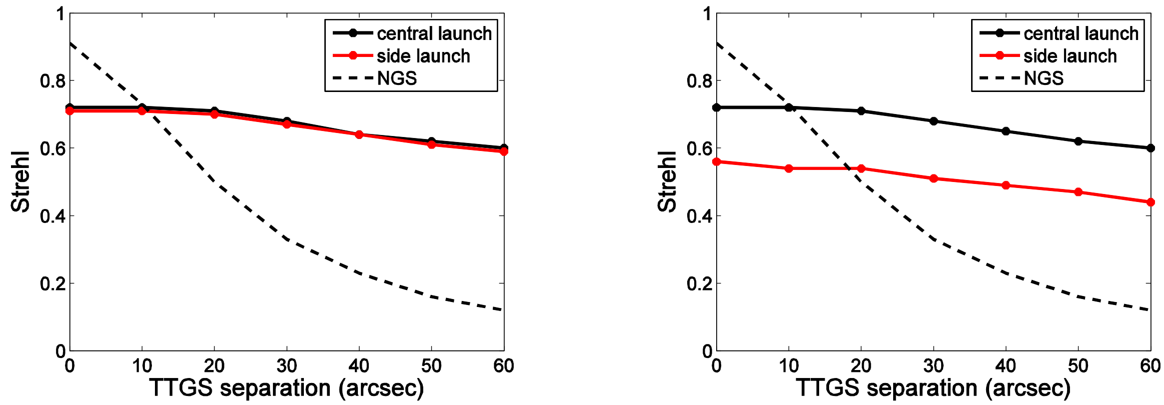


Figure 3: simulation results for a r_0 of 20 cm. Upper left, with a 7 arcsec field stop ; upper right, with a 5 arcsec one, and down with 4 arcsec. Only the cone effect, tilt-jitter and the fitting errors are considered.



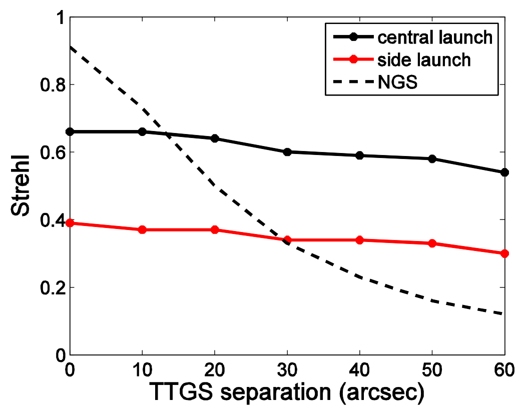


Figure 4: simulation results with a r_0 of 14 cm. Upper left, with a 7 arcsec field stop; upper right, with a 5 arcsec one, and down with 4 arcsec. Only the cone effect, tilt-jitter and the fitting errors are considered.

3.2 Performance as a function of the TTNGS magnitude

We have also performed simulations changing the TTNGS magnitude, in order to find the minimum magnitude required to correct the TT and the sky coverage associated to it.

We have used TTNGSs with magnitudes from 13 to 23, for three different values of the seeing that represent bad, average and good seeing conditions (i.e 7, 14 and 20 cm). The field stop used was 7 arcsec, the pixel scale 0.7 arcsec/pix and the image fwhm was 2 pixels. When launching the LGS from the centre, the results are plotted in Figure 5. At the left we have plotted the curve for a TTNGS at the centre of the FoV. We can see that for the bad seeing case, a TTNGS of minimum 16 magnitude is needed to reach the 10% Strehl that is in GTCAO specifications, represented by the horizontal line. We can see that in the case of good seeing conditions, the specified Strehl could be reached even with a very dim TTNGS. At the right we have plotted the curve for a TTNGS at 60 arcsec from the centre of the FoV. In this case for the bad seeing conditions, we need a TTNGS of minimum 15 magnitude to reach the 10% Strehl specified. In the case of good seeing conditions, again it could be reached even with a dim TTNGS.

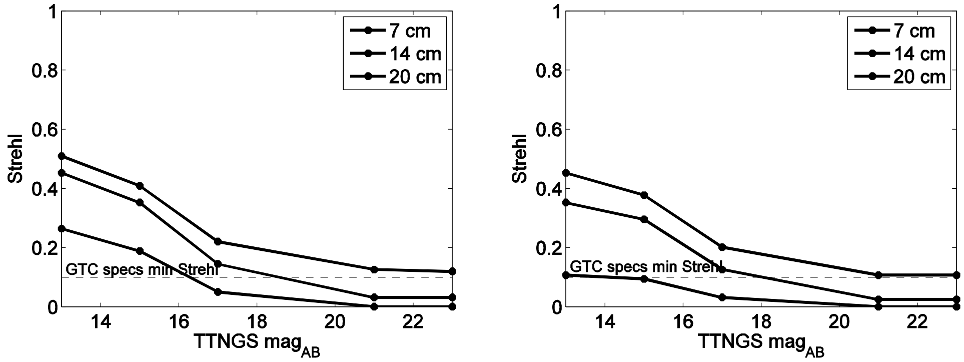


Figure 5: Strehl as a function of the TTNGS magnitude for different values of r_0 and a LGS launched from the centre. At the left the TTNGS is at the centre of the FoV, at the right it is at 60 arcsec from the centre. The horizontal lines show the value of the Strehl without a TTWFS. All errors included in the GTCAO budget are included.

4. SKY COVERAGE

With the calculated limiting magnitudes for the TTNGS we can compute the sky coverage that the LGS AO facility will reach for the three cases defined of bad, average and good seeing conditions. As explained in Schumacher et al.[6], we use the Guide Star Catalogue[7] to calculate the density of stars brighter than magnitude M per degree square for a given region:

$$P = 1 - \exp(-\pi r^2 \nu),$$

where ν is the density of stars brighter than magnitude M per degree square and r is the radius of the field where we want to find a TTNGS in degrees.

We have defined two main regions: the Galactic Centre and outside of it. In Table 3 we have summarized the results.

Seeing	**Limiting m_{AB} (up to 60 arcsec separation)**	**Sky coverage at galactic centre**	**Sky coverage outside galactic centre**
Good	na	100%	100%
Average	18	58%	42%
Bad	15	58%	40%

Table 3: sky coverage of the LGS AO facility for different seeing conditions using a TTNGS separated up to 60 arcsec from the centre of the field.

5. CONCLUSIONS

Launching the laser of the LGS facility from the side has an impact on the performance. In very good seeing conditions (r_0=20 cm), the performance suffers a 10% reduction if the field stop is 5 arcsec, and a 20% reduction if the field stop is 4 arcsec. In average seeing conditions (r_0=14 cm), it suffers a 15% reduction if the field stop is 5 arcsec, and a 25% reduction if the field stop is 4 arcsec.

With a field stop of 7 arcsec (image fwhm 1.4 arcsec), when the laser is launched from the centre and the TTNGS is in the centre of the FoV, the limiting magnitude of the TTNGS in case of bad seeing is 16.5, and in case of average seeing the system could use a 18.5 magnitude star to correct the TT. These figures were calculated considering that the minimum performance according to the specifications is 10%. If the TTNGS is at 60 arcsec from the centre of the FoV, the limiting magnitude of the TTNGS in case of bad seeing is 15, and in case of average seeing the system could use an 18 magnitude star to correct the TT. In the case of good seeing conditions, the specified Strehl could be reached even without a TTNGS, and in fact in the case of having the TTNGS at 60 arcsec from the centre of the field it is better not to use it at all. When the laser is launched from the side the results do not vary much, due to the large field stop that we have used.

With these limiting magnitudes we have computed the sky coverage for the three cases of bad, average and good seeing conditions, for two regions of the sky: the Galactic Centre and outside of the Galactic Centre. For average or bad conditions the sky coverage is 58% at the Galactic Centre. When looking outside the Galactic Centre in average conditions we can access 42% of the sky and 40% of it with bad seeing. And in good seeing conditions the sky coverage is virtually 100% since we can obtain the specified 10% Strehl even without a TTWFS. For comparison, with a NGS we need a magnitude of 13 to reach a 10% Strehl at 50 arcsec separation at average seeing conditions, therefore the sky coverage outside the Galactic Centre would be 9% instead of the 42% we get when using a LGS AO facility.

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