Which range of magnitudes for Layer Oriented MCAO?

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ABSTRACT

Layer Oriented MCAO is a promising technique attempting to perform wide field of view correction with Natural Guide Stars. In the extended concept of Multiple Field of View Layer Oriented MCAO the wavefront sensor field of view is enlarged to collect more photons from more Natural Guide Stars and, in principle, significant sky coverages at any galactic latitude are achieved using only Natural Guide Stars.

In this paper we address the problem of finding the best magnitude range for the Natural Guide Stars in order to achieve the best correction with the largest sky coverage in the Layer Oriented Multiple Field of View. For a given Field of View and sky direction we consider only the Natural Guide Stars within a given brightness range and we compute the equivalent integrated magnitude.

Then we correlate the contribution in sky coverage of the previously considered Natural Guide Stars and we extrapolate which is the magnitude class giving the largest sky coverage. Once identified the more suitable Natural Guide Star magnitude class we discuss the possible implications in the design of a Multiple Field of View Layer Oriented wavefront sensor and we give the order of magnitude for the main parameters, i.e., maximum number of Natural Guide Stars and detector characteristics.

Keywords: Multi-Conjugate Adaptive Optics systems, Layer oriented MCAO, Wavefront Sensors, Sky Coverage.

1. INTRODUCTION

Multi-Conjugate Adaptive Optics (MCAO, Beckers 1988, 1989, Ellerbroek 1994) has been proposed to extend the correction Field of View (FoV) typically limited in the classical Adaptive Optics (AO) systems (Beckers 1993). In a MCAO systems several Deformable Mirrors (DM) are conjugated to different altitudes above the telescope and the atmospheric correction in done in a three-dimensional way. Each DM corrects the part of the atmosphere which it is conjugated to, even if the vertical discretization is somewhat rough.

In order to reconstruct the vertical distribution of the atmospheric turbulence, different approaches have been proposed. Tallon and Foy (1990) introduced the concept of tomography to disentangle numerically the turbulence at fixed altitudes, using independent measurements obtained from an number of Guide Stars (GS) through classical Wavefront Sensors (WFS), like Shack-Hartmann or Curvature sensors. Later Ragazzoni, Marchetti and Rigaut (1999) introduced a more effective concept of modal tomography were the tomography approach is performed in modal way. The validity of the method has also been proven on the sky (Ragazzoni, Marchetti and Valente 2000) although in a preliminary form. At the same time the novel concept of layer-oriented has been introduced (Ragazzoni 2000; Ragazzoni, Farinato and Marchetti 2000) where many GSs are simultaneously sensed with a single WFS with several detectors conjugated at the DM conjugation altitudes. The signal from each detector drives its corresponding DM allowing efficient closed loop operations. Layer-oriented approach is extremely effective in terms of Signal-to-Noise Ratio optimization of the sensing process because it is possible to tune both the temporal and the spatial sampling for the temporal ($\tau_0$) and spatial frequencies ($r_0$) characteristic of the layer which the detector is conjugated to. Moreover the co-addition of the light of the GSs in a single plane allows lowering the requirements in GS brightness and, in this way, increasing the Sky Coverage when Natural Guide GSs are considered. It is clear why in the MCAO the WFS plays an extremely important role for the three-dimensional atmospheric turbulence sensing. In the layer-oriented approach any kind of pupil plane WFS could be suitable but a quite promising one is the Pyramid WFS (PWFS, Ragazzoni 1996). Furthermore an

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extension of the layer-oriented approach, called Multiple FoV (MFoV, Ragazzoni et al. 2002a; 2002b), allows a significant increasing the Sky Coverage using a larger FoV for the ground conjugated detector to collect light from more stars. Extremely Large Telescopes (Gilmozzi et al. 1998; Nelson 2000) can strongly benefit from the layer-oriented approach and moreover the NGS based Multiple FoV gives really competitive Sky Coverages with respect to Laser GSs based systems.

In the first section of this paper a general overview of the MFoV is briefly presented in order to identify the basic parameters involved in the problem. Then a detailed analysis of the WFS noise propagation is implemented and an estimation of the limiting magnitude for a given Strehl ratio degradation is obtained for a particular system case. The limiting magnitude is then correlated with the sky distribution of the NGSs and the for sky coverage values at different galactic latitudes are figured out. For each single case the optimal magnitude range for the NGSs and a related maximum number is computed and the detailed sky coverage is shown. Finally some general considerations for the design of a MFoV Layer Oriented Pyramid WFS are given in particular for the maximum number of pyramids and for the detector characteristics. In this paper a two conjugation altitudes system is considered but the general concept can be extended to any MCAO system with more conjugation altitudes.

2. MULTIPLE FIELD OF VIEW LAYER ORIENTED

In MCAO the most demanding correction is that of the ground layer where most the part of the turbulence is concentrated. In order to overcome this problem a variation to the classical Layer Oriented MCAO has been proposed. In the MFoV the FoV of the detector conjugated to the ground layer is larger than the FoV corrected by the MCAO system. Enlarging the FoV allows sensing simultaneously more NGSs and this feature has a double effect:

- for a given direction on the sky the photon flux per sub-aperture collected is statistically larger by a factor roughly proportional to the FoV area, that means an higher SNR ratio in the detection process;
- for a given SNR the NGS can be fainter by a factor roughly inverse proportional to the FoV area, that means a larger sky coverage.

The ground conjugated detector senses the NGSs included in the enlarged FoV but those included in the corrected FoV that is smaller and located at the center of the larger FoV.

![Figure 1 MFoV Layer Oriented concept. The FoV of the ground conjugated detector is enlarged to collect the light from more NGSs increasing in this way both the SNR in the detection process and the sky coverage.](image-url)
Practically speaking the ground conjugated detector FoV is a ring and the central hole is the corrected FoV. The high altitude conjugated detector is looking only at the stars included in the corrected FoV, that is, the two detectors don’t mutually share the light of any NGS. The two detectors will sample the wavefront at the spatial and temporal frequencies typical of the corresponding atmospheric altitude. The signals from the detectors are used to control the corresponding DM conjugated at the same altitude.

Since the ground conjugated detector is looking at a larger FoV the corresponding measured wavefront is affected by a certain amount of anisoplanatism being the NGSs distributed in a FoV much than the corrected one. In order to compensate for this additional anisoplanatism injected in the system, part of the NGS light of the high altitude conjugated detector is sent to a second ground conjugated detector. This detector has a much coarser spatial sampling since the wavefront perturbation of the injected anisoplanatism is smoothed by the effect of the superposition of the different NGS footprints spread over the large FoV. The signals from this detector are mixed with the previous ones to control the ground conjugated DM. A schematic representation of a MFoV system is shown in Figure 1.

3. LIMITING MAGNITUDE FOR THE WAVEFRONT SENSING

For limiting magnitude calculation we considered only the noise injected in the system by the WFS detection process. It is supposed to use a multi Pyramid WFS and the additional gain of the pyramid (Ragazzoni and Farinato 1999) is not considered, that is, the Pyramid WFS behaves as a Shack–Hartmann WFS (SHWFS).

We consider the limiting magnitude for the MFoV system as the magnitude giving a Strehl degradation due to the WFS detection process of 0.5 with respect of the infinite SNR case (infinite bright NGS).

3.1. Noise models

In order to compute the limiting magnitude we considered two different model of SHWFS noise: the Rigaut and Gendron model (R&G, 1992) and the Rousset, Primot and Fontanella model (RPF, 1987).

In R&G the wavefront variance error $\sigma^2$ in rad$^2$ is given by the following relationships:

$$
\sigma^2 = \left( \frac{\lambda_{wfs}}{\lambda_{cor}} \right)^2 \frac{2\pi}{SNR^2} \sum_{i=2}^{J_{max}} p_i , \quad SNR = \frac{N_{ph}}{\sqrt{N_{ph} + 4 RON^2}} .
$$

where $\lambda_{wfs}$ is the wavefront sensing wavelength, $\lambda_{cor}$ is the correcting wavelength, $N_{ph}$ is the number of photons detected per sub-aperture and integration time and $RON$ is the detector pixel read-out noise. It is supposed that the sub-aperture is 2 x 2 pixels. The coefficients $p_i$ are the noise propagation coefficients of the $i$-th Zernike polynomial for the SHWFS and are obtained using the following relationships:

$$
p_i = -2.00 \log (n_i + 1) - 0.76 , \quad p_i = -2.05 \log (n_i + 1) - 0.53 .
$$

where the left equation is valid for all the polynomials of same radial degree $n_i$ but the last two and the right equation is valid for the last two polynomials of each radial degree $n_i$. The coefficients $p_i$ are summed up to the maximum reproducible Zernike polynomial $J_{max}$.

In RPF the wavefront variance error $\sigma^2$ in rad$^2$ is given by the following relationships:

$$
\sigma^2_{ph} = \frac{\pi^2}{2} \frac{1}{N_{ph}} \left( \frac{N_t}{N_d} \right)^2 , \quad \sigma^2_{ron} = \frac{\pi^2}{3} \frac{RON^2}{N_{ph}^2} \left( \frac{N_s}{N_d} \right)^2 \frac{N_s^2}{N_{ph}^2} , \quad \sigma^2 = \sigma^2_{ph} + \sigma^2_{ron} .
$$

where $\sigma^2_{ph}$ is the variance error related to the photons shot and $\sigma^2_{ron}$ is the variance error related to the detector RON. $N_t$ is the linear number of pixel per seeing disk, $N_d$ is the linear number of pixel per FWHM of the diffraction limited sub-aperture and $N_s$ is the linear number of pixel used for the centroid measurement after windowing. $N_{ph}$ and $RON$ have the same meaning of the R&G relationships. In this paper we assumed $N_t = N_s = 2$.
3.2. MFoV system parameters

The MFoV case of this paper consists of a two conjugated DM MCAO system with three loops as described in Sect. 2. The limiting magnitude is computed for each of the three loops taking into account the different loop characteristics. The simulated system has the following parameters:

- Telescope diameter: 8 m
- Corrected FoV: 2 arcmin
- DM conjugated altitudes: 0 and 7 Km
- Ground conjugated detector FoV: 6 arcmin (ring 1 → 3 arcmin radius)
- WFS wavelength: 0.7 µm
- WFS bandwidth: 0.5 µm
- Correction wavelength: 0.8 µm
- Global throughput: 0.2 (including WFS bandwidth and detector QE)
- Detector RON: 4e
- Zero Point: 1.0x10^{11} photons/sec/m²/µm
- Seeing @ 0.5 µm: 0.60 arcsec
- r_0 @ 0.8 µm: 0.30 m
- Sub-aperture size: GL6=0.33 m, HL2=0.90 m, GL2=5.43 m
- Wind speed @ 0 and 7 Km: 10 m/s, 20 m/s
- Integration time: GL6=0.010 s, HL2=0.014 s, GL2=0.084 s

where GL6 is the ground conjugated detector 6 arcmin FoV, HL2 is the high altitude conjugated detector 2 arcmin FoV and GL2 is the ground conjugated detector 2 arcmin FoV with a coarser spatial sampling due to the smoothing effect of the large 6 arcmin FoV. The wind speed associated to the GL2 is that of HL2 since the injected anisoplanatism has the temporal behavior of the high altitude layer.

For the limiting magnitude calculation the dark current of the detector and the sky background are pretty negligible and have not been considered.

For the HL2 the pupil non-overlap is taken into account decreasing the related photon flux by a factor equal to the ratio between the 2 arcmin FoV footprint at 7 Km and the telescope pupil areas.

3.3. Limiting magnitudes

The limiting magnitudes for the three MFoV loops have been computed using the parameters of Sec. 3.2 with both the R&G and RPF models. As mentioned above we consider the limiting magnitude for the MFoV system as the magnitude giving a Strehl degradation due to the WFS detection process of 0.5 with respect of the infinite SNR case (infinite bright NGSs). After an optimization process, the total error variance has been distributed between the loops with the following weights: GL6=0.40, HL2=0.55, GL2=0.05

<table>
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<th>R&amp;G</th>
<th>RPF</th>
<th>Average</th>
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<tr>
<td>GL6</td>
<td>14.60</td>
<td>14.45</td>
<td>14.52</td>
</tr>
<tr>
<td>HL2</td>
<td>16.63</td>
<td>16.30</td>
<td>16.45</td>
</tr>
<tr>
<td>GL2</td>
<td>23.03</td>
<td>21.16</td>
<td>21.73</td>
</tr>
</tbody>
</table>

Table 1 Limiting magnitudes for the three MFoV loops.

The two models give approximately the same results and an average in flux between the two set of values has been taken as limiting magnitude for the purposes of this paper.

It is worth noting that the GL2 is ~5.3 magnitudes fainter of HL2 and with a proper light splitting it is always possible to send 1% of the HL2 light to GL2 achieving easily the limiting magnitude requested without affecting the photon budget of HL2. For this reason we don’t consider the contribution of GL2 in the next section.

Since any Layer Oriented system has the capability to co-add the light of the NGSs on the different detectors, hereafter we consider the limiting magnitude as integrated limiting magnitude given by the contribution of all the NGSs sensed by a specific detector.
4. NGS NUMBER AND INTEGRATED MAGNITUDE

The density of stars and consequently the integrated magnitude for a given FoV is changing with the location of the observed target with respect the galactic latitude and longitude. The integrated magnitude is a complex function of the star density and luminosity distribution and an accurate modelization of the potential NGSs on the sky is required to figure out realistic sky coverage for the MFOV.

For this approach the Bahcall and Soneira model (1980) has been implemented. In Table 2 is given the comparison of the model as implemented in this paper and the integrated star counts at the North Galactic Pole for different photometric bands (in parenthesis, Bahcall and Soneira 1981): the model and the observations are in good agreement.

<table>
<thead>
<tr>
<th>m_r</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0.9 (0.9)</td>
<td>2.0 (2.6)</td>
<td>4.4 (4.4)</td>
<td>10 (11)</td>
<td>21 (25)</td>
<td>43 (48)</td>
<td>86 (91)</td>
<td>162 (163)</td>
</tr>
<tr>
<td>V</td>
<td>1.5 (1.9)</td>
<td>3.5 (3.7)</td>
<td>7.7 (7.6)</td>
<td>17 (18)</td>
<td>35 (37)</td>
<td>73 (74)</td>
<td>145 (135)</td>
<td>267 (245)</td>
</tr>
<tr>
<td>R</td>
<td>2.2 (3.1)</td>
<td>5.1 (5.1)</td>
<td>11 (12)</td>
<td>25 (27)</td>
<td>54 (57)</td>
<td>112 (108)</td>
<td>219 (205)</td>
<td>394 (382)</td>
</tr>
<tr>
<td>I</td>
<td>3.1 (4.1)</td>
<td>7.1 (7.2)</td>
<td>16 (16)</td>
<td>36 (38)</td>
<td>79 (80)</td>
<td>168 (158)</td>
<td>327 (317)</td>
<td>585 (526)</td>
</tr>
</tbody>
</table>

Table 2 Comparison between the integrated star counts at the North Galactic Pole computed with the Bahcall and Soneira model and those measured on the sky for different magnitudes and photometric bands (in parenthesis).

In this work only NGSs in the R band ($\lambda_{\text{wfs}} = 0.7$ $\mu$m) magnitude range from 10 to 20 have been considered.

4.1. Integrated magnitude computation

The integrated magnitude distribution for different galactic directions has been computed for the 2 arcmin FoV and the ring of 6 arcmin FoV in the following way:

- for a given galactic coordinate, a field of 1 square degree is generated with the related star density and star luminosity distribution. The stars are randomly placed over the whole field and the number is generated using Poissonian distribution with mean equal to the star density at a given magnitude;
- a circular 2 arcmin FoV and the ringed 6 arcmin FoV are convolved via Fast Fourier Transform with the star field. The result is a map of star number and integrated magnitude over the whole 1 square degree field;
- the sky occupation for a given star number and integrated magnitude is retrieved for both FoV (Figure 2);
- for each sky direction the process is repeated 20 times and the results are averaged;
- the process is implemented for different magnitude ranges within the main one (R magnitude 10→20).

Figure 2 Result of the convolution of the star field with the two FoV. The points of the field where the FoV footprints superimpose are the direction where the same FoV is able to include more stars.
The output data consist of a cube where each single element represents the sky occupation or sky coverage (in percent) for a given NGS number and integrated magnitude. Seven different Galaxy directions have been studied: the galactic pole $b = 90^\circ$, an intermediate latitude $b = 50^\circ$ and $l = 0^\circ, 90^\circ, 180^\circ$, and the galactic plane $b = 20^\circ, l = 0^\circ, 90^\circ, 180^\circ$.

Also many magnitude ranges have been considered: here we report only the results for a R magnitude range of 5 scanning the full range (10-14,11-15,12-16,….,16-20) and the results obtained with the full R magnitude range.

4.2. Sky coverage bi-dimensional plots

In Figure 3 are shown two examples of bi-dimensional sky coverage plots obtained with the process mentioned in Sec. 4.1. The sky occupation is plotted against both the number of NGSs and the integrated magnitude for a given FoV and a given magnitude range.

![Figure 3 Sky coverage plots for the Galactic Pole for the whole 10→20 R magnitude range. In the case of 2 arcmin FoV (left) the integrated magnitude is relatively faint and the number of NGS small. For the ringed 6 arcmin FoV (right) the integrated magnitude is much brighter and the number of contributing stars is much larger.](image)

In the case of Figure 3, the full NGS R magnitude range at the galactic Pole is considered. It is clear how different is the behavior between the two FoVs. For the small 2 arcmin FoV (left) the integrated magnitude is relatively faint and the number of contributing NGSs is small. As soon as the FoV increases (right) the integrated magnitude is much brighter and the number of contributing stars is larger. It is clear from these plots how big the potential of the MFoV technique is. The Table 1 shows that the ground layer is more demanding than the high altitude one by roughly two magnitudes and, when the sky is poorly populated, the ground layer requirement can met only in a limited number of cases. In the MFoV the probability to have brighter integrated magnitudes is much higher and it transfers to larger sky coverage.

The detailed study of the different behavior of the two FoVs allows to figure out the requirements in terms of NGS number and magnitudes. In principle it is possible to produce, at a conceptual level, the design for a future MFoV system both for 8-m class telescope and for an Extremely Large Telescope.
5. SKY COVERAGE AND NGS NUMBER

Using the sky coverage plots it is possible to retrieve the MFOV sky coverages at different galactic directions. The NGS magnitude range used for this analysis is 5 and in some particular cases the full NGS magnitude range has been considered. The sky coverage values are obtained integrating the bi-dimensional plots between selected limits of NGS number and integrated magnitudes. The NGS number considered is ranging between 3 (minimal coverage of the high altitude FoV footprint) and 12 while the integrated magnitude is ranging between 0 and the limits of Table 1. The final sky coverage is obtained multiplying the sky coverage of the 2 arcmin FoV by that of 6 arcmin FoV.

5.1. Sky coverage at the Galactic Pole

The sky coverage plots at the Galactic Pole for both FoV are shown in Figure 4. For the 2 arcmin FoV a maximum sky coverage of 0.15 is obtained with no more than 6 faint NGSs ($m_R=16-20$).

![Figure 4 Sky coverages at the Galactic Pole for the NGS magnitude range of 5.](image)

![Figure 5 Sky coverage plotted against magnitude class.](image)
For the 6 arcmin FoV a maximum sky coverage of 0.80 is obtained with around 12 brighter NGSs ($m_R=13-17$). The final sky coverage is $0.15 \times 0.80 = 0.12$. The variation of the sky coverage with respect to the magnitude class for both FoV is shown in Figure 5.

### 5.2. Intermediate galactic latitudes: $l = 90^\circ, b = 50^\circ$

The sky coverage plots at intermediate galactic latitudes ($l=90^\circ, b=50^\circ$) are shown in Figure 6. For the 2 arcmin FoV a maximum sky coverage of 0.33 is obtained with no more than 8 faint NGSs ($m_R=16-20$).

![Figure 6 Sky coverages at intermediate galactic latitudes ($l=90^\circ, b=50^\circ$) for the NGS magnitude range of 5.](image)

For the 6 arcmin FoV a maximum sky coverage of 0.89 is obtained with around 12 brighter NGSs ($m_R=12-16$). The final sky coverage is $0.33 \times 0.89 = 0.29$. The variation of the sky coverage with respect to the magnitude class for both FoV is shown in Figure 7.

![Figure 7 Sky coverage plotted against magnitude class.](image)
5.3. Galactic plane: $l = 90^\circ, b = 20^\circ$

The sky coverage plots at a region close to the galactic plane ($l=90^\circ, b=20^\circ$) are shown in Figure 8. For the 2 arcmin FoV a maximum sky coverage of 0.89 is obtained with around 10 relatively bright NGSs ($m_R=14-18$).

![Figure 8 Sky coverages at the galactic plane ($l=90^\circ, b=20^\circ$) for the NGS magnitude range of 5.](image1)

For the 6 arcmin FoV a maximum sky coverage of 0.93 is obtained with around 12 bright NGSs ($m_R=11-15$). The final sky coverage is $0.89 \times 0.93 = 0.86$. The variation of the sky coverage with respect to the magnitude class for both FoV is shown in the plot of Figure 9.

The sky coverage for the MFoV follows the behavior of the galactic star distribution. In the regions poor of stars, a modest sky coverage is obtained with few faint NGSs at least for the 2 arcmin FoV. The sky coverage increases as soon as we approach to the galactic plane where numerous brighter NGSs are able to satisfy the integrated magnitude requirements for both FoV. The NGSs for the 6 arcmin FoV are always brighter than those for the 2 arcmin FoV.

![Figure 9 Sky coverage plotted against magnitude class.](image2)
5.4. Sky coverage summary

In the cases of poorly populated star fields, the sky coverage can be significantly increased by considering all the NGSs in full magnitude range. In Figure 10 is shown the sky coverage obtained when all the NGSs present in the field are used, for the galactic pole and intermediate galactic latitude cases, both for the 2 arcmin FoV. The global sky coverage increases from 0.12 to 0.21 for the galactic pole and from 0.29 to 0.43 for the intermediate galactic latitudes. For both cases the maximum number of NGS considered is 8.

Figure 10 Sky coverage at the galactic pole and at intermediate galactic latitudes when all the NGSs present in the FoV are used. The plots refer to the 2 arcmin FoV case.

In Table 3 are reported all the sky coverages obtained for different galactic directions. In Table 4 are shown the different magnitude ranges and the maximum number of NGSs used to achieve the integrated magnitude required.

<table>
<thead>
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<th>b=50°</th>
<th>b=90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>l=0°</td>
<td>0.92 x 0.93 = 0.86</td>
<td>0.80 x 0.85 = 0.68</td>
<td>0.26 x 0.80 = 0.21</td>
</tr>
<tr>
<td>l=90°</td>
<td>0.89 x 0.93 = 0.83</td>
<td>0.48 x 0.89 = 0.43</td>
<td>-</td>
</tr>
<tr>
<td>l=180°</td>
<td>0.81 x 0.93 = 0.75</td>
<td>0.30 x 0.87 = 0.26</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3 Sky coverage for different galactic directions. The values in italics are obtained using all the NGS of the full magnitude range.
Table 4 Magnitude ranges and maximum number for the NGSs at different galactic directions. The values in italics refer to the full NGS magnitude range.

<table>
<thead>
<tr>
<th></th>
<th>$b=20^\circ$</th>
<th></th>
<th>$b=50^\circ$</th>
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<td>12</td>
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<td>10</td>
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<td>$10-20$</td>
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</table>

6. REQUIREMENTS FOR THE MFOV LAYER ORIENTED WFS

Using the results obtained above, it is possible, up to a certain extent, to figure out the requirements for a theoretical pyramid based MfoV Layer Oriented WFS. The two main sensing channels (GL and HL) exhibit different characteristics depending on the magnitude and the number of the sensed NGSs. The HL channel shall be able to sense relatively faint NGSs, with magnitude ranging from 12/14 to 20. Since this channel is measuring the atmospheric distortion at a significant altitude above the telescope, the non-overlap of the pupil footprints affects in a significant way the sensing process and this effect is much more severe being the NGSs are faint. Particular care has to be taken when designing the HL channel. The optical train shall be optimized to maximize the throughput, reducing the number of optics and using proper coatings having the maximum efficiency centered at the wavelength where the QE of detector is the highest. The detector shall follow the same criteria in terms of noise and sensitivity. The HL channel detector shall have high quantum efficiency in the whole sensitivity range and low RON and dark current. The limiting integrated magnitude increases by one magnitude if the RON is below 1 e$^{-}$, a performance not so far from the reality if considering, for example, the new generation L3Vision CCD from Marconi. The same gain can be obtained increasing the whole system throughput by a factor 2.5 and in our case it means a global throughput of 0.5, a performance very difficult to achieve. A gain of 1 magnitude increases the sky coverage by almost a factor 2 for the fainter NGSs cases and this gain comes only from the HL channel. The GL channel is never magnitude limited and a gain of one magnitude doesn’t bring almost anything in term of sky coverage. The maximum number of sensed NGS for the HL channel can be easily limited to 8-10 without loosing significant portions of sky coverage. The GL channel is less demanding in terms of noise and sensitivity. It has been demonstrated that this channel in never magnitude limited and for all the galaxy directions the channel limiting magnitude is well above the available integrated magnitudes given by the NGSs present in the larger FoV. Even if particular care has to be taken when designing the system, neither the throughput nor the detector noise and sensitivity affect dramatically the final sky coverage. The throughput and the detector RON considered in this paper are well within the standard performance of the available technology. On the other hand, a larger number of NGSs is required but the maximum number doesn’t exceed the 12-14. The third channel, which is conjugated to the ground to compensate the anisoplanatism injected by the channel with larger FoV, is not demanding at all as shown in Sec. 3.3.

7. CONCLUSIONS

It has been shown that the MfoV Layer Oriented approach brings important advantages in terms of sky coverage when using only NGSs for wavefront sensing. The problem of the ground layer is overcome by enlarging the FoV of the detector conjugated at the ground. Since more stars are available, it is much easier to achieve the required limiting magnitude because both the large number of stars and the increased probability to find brighter NGS in the WFS FoV. The ground layer loop is not driving the sky coverage anymore and the lead is taken by the high altitude loop that is, however, less demanding in term of photons. At faint regimes the MfoV performs much better than the classical Layer Oriented both in terms of correction and in terms of sky coverage. The enlarged FoV doesn’t degrade significantly the correction performance since a third loop is compensating the ground layer for the injected anisoplanatism. This third loop, since it has a much coarser sampling, requires a very small amount of photons that can be obtained removing a negligible part of flux from the high altitude conjugated loop.
With the assumptions taken in this paper both for the MCAO system and for the atmosphere, we obtained the sky coverage map for different directions of the sky and the values are remarkably high even at the galactic pole, considering that only NGS are used for wavefront sensing. The large FoV GL can use systematically brighter NGS than the HL even if the number of NGS is larger.

The role of the two loops is exchanged and the HL channel requires more attention for practical implementation both from the optics and the detector point of view. By the way, a lower noise detector can increase the sky coverage up by a factor two for the cases where only faint NGS are available, and such devices are not far to be a reality in the next coming years.

The MFoV Layer Oriented looks very promising in opening a way to large sky coverage using only NGS for MCAO wavefront correction at shorter wavelengths, and the demonstrator projects in development these years will help in giving a much clearer answer to the feasibility of the Layer Oriented technique.

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