Generalized SCIDAR measurements at Mt. Graham

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ABSTRACT

We present the results of Generalized SCIDAR (GS) measurements of the vertical distribution of the optical turbulence above Mt. Graham in south-eastern Arizona. First results of an on-going site-characterization campaign covering 16 nights, distributed over 1 year are presented. The measured C_N^2 profiles show that most of the turbulence above Mt. Graham is concentrated near the ground and that Mt. Graham is excellently suited for astronomical observations in terms of seeing, isoplanatic angle and coherence time. A fine sampling of the complete atmospheric turbulence can be achieved by combining the data from GS analyzed in conventional fashion with a vertical resolution of ~1 km and those obtained with a newly developed method, based on GS, with a vertical resolution of ~25 m in the first 1500 m above the ground. Moreover, the impact of the retrieved turbulence profiles on Adaptive Optics systems, in particular, the optimal conjugated heights of the Deformable Mirrors optimized for narrow as well as large FOVs, are estimated.

INTRODUCTION

The LBT (Large Binocular Telescope) is currently being commissioned at Mt. Graham and will make use of a sophisticated AO and MCAO system. In order to optimize the design of the AO system and to achieve the best possible performance, it is essential to know the turbulence characteristics above the telescope. For these reasons, a dedicated site-characterization campaign with a SCIDAR instrument mounted to the VATT to measure the atmospheric turbulence above Mt. Graham is currently being performed.

CN2 PROFILES

Using all the C_N^2 profiles, the median profiles for each night (fig. 2) and for all the data (fig. 1) have been calculated.

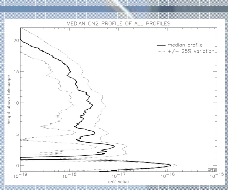

Figure 1: The median C_N^2 profile using all the measured C_N^2 profiles so far, again after the subtraction of the dome-seeing.

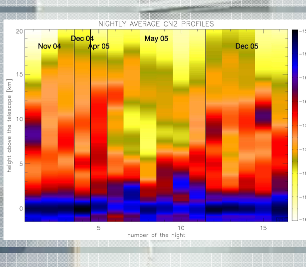

Figure 2: The mean C_N^2 profile for all the single nights, after subtraction of the dome-seeing. The strength of the turbulence is color-coded, with blue representing strong and yellow weak turbulence.

ASTRO-CLIMATIC PARAMETERS

So far we have measured ~10 000 C_N^2 profiles, distributed over 16 nights in 2004 and 2005. From the measured cross-correlation images, we furthermore determined the wind-speed profiles and the dome-seeing as described in Avila et al.[1]. Using these data, all the astro-climatic parameters have been calculated (table 1 & fig. 3), which turn out to be very similar to the values measured with SCIDAR instruments at other good astronomical sites.

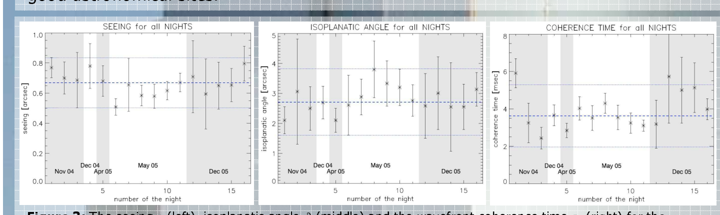

Figure 3: The seeing ε (left), isoplanatic angle ϑ (middle) and the wavefront coherence time τ_0 (right) for the individual nights as determined from the C_N^2 (after subtraction of the dome-seeing) and wind speed profiles measured with the SCIDAR. The error bars indicate the variation of the astro-climatic parameter during each of the single nights, the dashed line is the median value and the dotted lines are the standard deviation using all the C_N^2 profiles.

Site	Duration	Seeing	Isoplananatic Angle	Coherence time
Mauna Kea[2] (without ground-layer)	20 nights	0.5″	1.9″	–
San Pedro Martir[3]	27 nights	0.71″	1.9″	6.5 msec
Cerro Tololo[4]	24 nights	0.85″±0.35″	2.1″±0.84″	3.0 msec
La Palma[5] (median seeing for single nights)	34 nights	0.78″ – 1.42″	1.3″	–
La Silla[6] (with dome-seeing)	30 nights	1.30″	2.1″	–
Mt. Graham	**16 nights**	**0.67″±0.17″**	**2.7″±1.1″**	**4.2±1.7 msec**

Table 1: The median seeing ε, isoplanatic angle ϑ and the wavefront coherence time τ_0 as measured at Mt. Graham in comparison to SCIDAR observations at other astronomical sites.

HIGH-VERTICAL-RESOLUTION SCIDAR

The vertical resolution for conventional Generalized SCIDAR is limited by the scintillation effect to ~1km at the ground[7] (fig. 1). For each layer, the FWHM of the associated peak in the auto-correlation images corresponds to a vertical range of ~1km (fig. 4). This means that if the distance between two turbulent layers is smaller, their respective correlation peaks overlap, and the layers cannot be separated anymore. However, for Multi-Conjugate Adaptive Optics systems, which correct single layers, it would be highly desirable to obtain C_N^2 profiles with a higher vertical resolution. To achieve optimal performance, it is essential to know the location and the strength of these layers and especially the inner structure of the ground-layer, which usually contains most of the turbulence (fig. 1).

If the peaks in the correlation frames corresponding to different turbulent layers could be somehow separated, the vertical resolution might be improved. Such a possibility is given for the cross-correlation images (fig. 4), where the correlation peaks are additionally shifted according to the wind-speed in the corresponding turbulent layer. The idea is therefore to use the temporal cross-correlation images instead of the auto-correlation images to determine the C_N^2 profile[8].

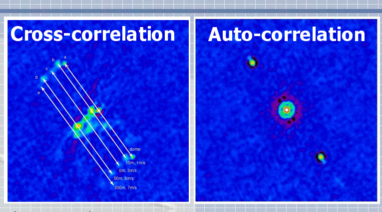

Figure 4: A sample of a cross- and auto-correlation image, measured for a binary with 35″ separation.

In the cross-correlation image, each turbulent layer produces a "triplet" (a central and two lateral peaks). The shift of the central peak is related to the wind-speed in that layer and the separation of the two lateral peaks corresponds to the height of the layer above the telescope. In such a case, layers which are close together in altitude, but have a different wind speed (Δv~0.5m/s) can still be separated. This is contrary to the auto-correlation image, where the single peaks overlap.

For the HVR method, the height of the layer is calculated from the separation of the lateral peaks (can be done with a precision of 25m) and the C_N^2 value from the intensity of the central peak in the cross-correlation image.

In this particular case, there is one layer inside the dome (a), two layers just outside the dome (b,c), but with different wind speeds, a very strong layer at around 50m (d) above the VATT and another layer at ~200m (e).

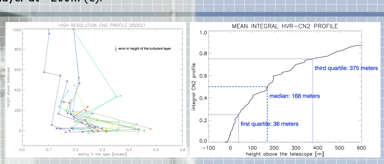

Figure 5: Left: The seeing in single layers as retrieved with the high-vertical resolution method for one night. The uncertainty in the height of the layers ~25m. A weak layer is located just outside the dome, but the strongest layer is for most of the time at around 50m above the telescope, and another layer at ~350m.

Right: The cumulative C_N^2 profile, which is a measure for the total amount of turbulence below a given altitude, as determined by combining the conventional and the high-vertical resolution SCIDAR technique. Half of the total atmospheric turbulence is below 168m above the ground.

Optimal conj. heights for DMs in MCAO

LINC-NIRVANA[9] is a Fizeau interferometer currently being developed for the LBT. It will use a MCAO system with two deformable mirrors (DMs), where the conjugation height of the high-layer DM can be freely adjusted. To calculate the optimal conjugated heights of the DMs, we used a semi-analytic model[8,10,11] to calculate a filtered C_N^2 profile after correction of the AO system. From this residual C_N^2 profile, the Fried parameter (and thus the Strehl-ratio on-axis) and the isoplanatic angle can be calculated. The optimal height of the DM is then given by the altitude for which the Strehl / isoplanatic angle is maximal.

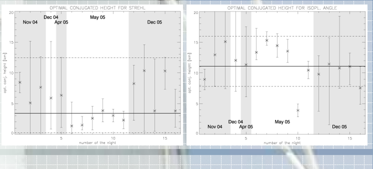

Figure 6: The optimal conjugated height above the telescope of the high-layer DM of LINC-NIRVANA in the case of highest Strehl ratio on-axis (left) and in the case for largest isoplanatic angle (right). For optimal Strehl-ratio it is important to correct the strongest layers (which are close to the ground, fig. 2), whereas for large isoplanatic angle the turbulent layers at high altitude have to be corrected. For both criteria there is a significant seasonal variation apparent. Due to the strong turbulence in the ground-layer, the ground-layer DM should be always conjugated to ~100m above the ground.

CONCLUSION

We presented the results of 16 nights observations with a SCIDAR at the VATT on Mt. Graham. The retrieved astroclimatic parameters are comparable to other good astronomical sites, the optimal conjugated height for the high-layer DM when using the criteria for highest Strehl is ~3.3km and for the isoplanatic angle ~11.1km. However, more data is required to confirm the observed seasonal trends in the vertical structure of the turbulence. Further GS runs at Mt. Graham are planned as part of the FOROT Project activities.

Furthermore, a new method was presented to retrieve C_N^2 profiles with a high vertical resolution of ~25m in the first 1 500m above the telescope. It is based on the analysis of temporal cross-correlation images of the scintillation pattern in the telescope pupil as measured with a Generalized SCIDAR instrument and on using a wide binary star (~35″ separation). With this vertical resolution, the inner structure of the ground-layer can be resolved, showing a variety of layers, with the strongest turbulent layer located at ~50m above the telescope. Half of the total turbulence in the atmosphere was found to be located within ~170m above the ground. This concentration of the turbulence very close the ground underlines the sensitivity of the achievable image quality on the actual position of the telescope on the mountain.

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