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Observations of the dynamic turbulence above La Palma using Stereo-SCIDAR

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ABSTRACT

Stereo-SCIDAR is a generalised-SCIDAR instrument which is used to characterise the atmospheric optical turbulence in terms of strength (C_n^2) and wind velocity profile using the triangulation technique and an optical binary star. Stereo-SCIDAR differs from most other SCIDAR instruments in that, instead of overlapping pupil images on a single detector, the image of each star is recorded on a separate EMCCD. Separating the pupil images in this way leads to several advantages, including better signal to noise ratios, larger useable magnitude difference of the target stars and reliable automated wind velocity measurements. The data is analysed and made available to observatory systems in real-time. Here we review the Stereo-SCIDAR technique and present recent results from the instrument on the Isaac Newton Telescope, La Palma.

Keywords: Adaptive Optics, Astronomical Instrumentation, Atmospheric Characterisation, Turbulence Profiling

1. INTRODUCTION

As Adaptive Optics (AO) systems become more sophisticated, a detailed and accurate estimate of the atmospheric turbulence profile is required for instrument design, performance validation and optimisation. This profile can be retrieved from the AO telemetry data itself[1] or from the an external profiler, such as Stereo-SCIDAR.[2,3] Here we present some example profiles from the Stereo-SCIDAR on the 2.5 m Isaac-Newton Telescope (INT), La Palma, and suggest a few reasons why an external profiler would be useful for the next generation of Extremely Large Telescopes (ELTs).

2. STEREO-SCIDAR

SCIDAR[4] (SCIntillation Detection And Ranging) is a technique to profile the vertical distribution of atmospheric turbulence by triangulation. The distance to a turbulent layer is estimated by measuring the spatial displacement of the scintillation patterns from two target stars. The strength of the turbulence is related to the magnitude of the covariance peak (figure 1). The technique can be extended by conjugating the detectors to an altitude below the telescope and in this way the Generalised-SCIDAR method can also be used to measure the turbulence at the ground.[5]

Stereo-SCIDAR is an instrument designed to measure the vertical profile of the optical turbulence with high-altitude resolution and high-sensitivity. Stereo-SCIDAR is based on the Generalised-SCIDAR technique.

In contrast to most SCIDAR instruments, Stereo-SCIDAR uses two cameras, one to image the defocussed pupil of each of the two target stars. A reflective wedge near to the focal plane is used to separate the light from the two target stars (figure 2). By doing this Stereo-SCIDAR has increased sensitivity to weaker layers, can operate with a larger difference in brightness of the target stars and has only one covariance peak per turbulent layer. The latter lends itself to automated turbulence velocity identification of the full atmosphere.[6,7] In this way Stereo-SCIDAR can be used to measure the optical turbulence with the same altitude resolution that the future ELT will achieve.[7]

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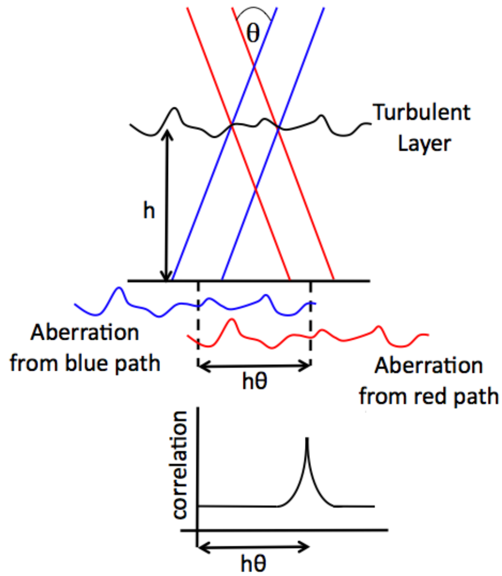

Figure 1. If a turbulent layer at height, h, is illuminated by two stars of angular separation, θ, then two copies of the aberration will be made on the ground separated by a distance $h\theta$. By cross correlating either the centroid positions from a Shack-Hartmann wavefront sensor (SLODAR) or the intensity patterns (SCIDAR) we can triangulate the height of the turbulent layer and the amplitude of the correlation peak corresponds to the strength of the layer.

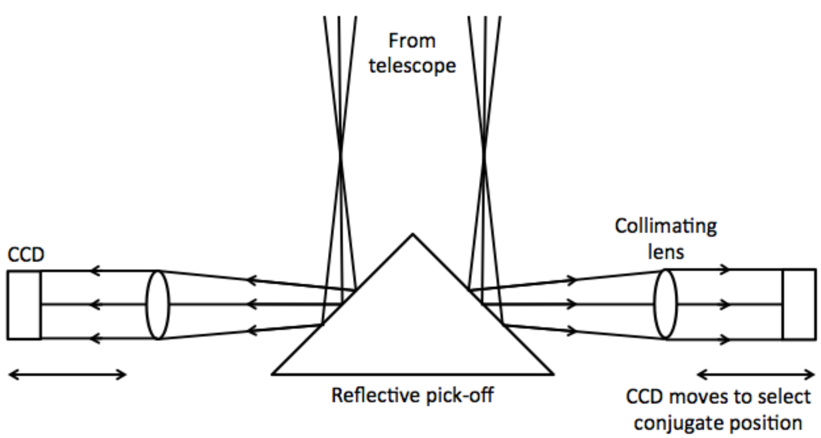

Figure 2. Stereo-SCIDAR uses a prism near the focal plane to separate the light from each of the target stars.

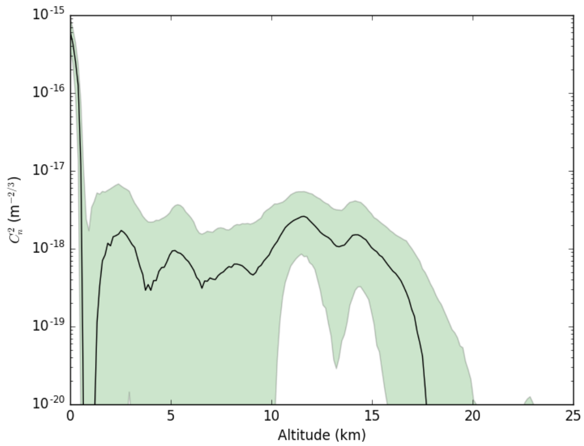

Figure 3. Median optical turbulence profile from Stereo-SCIDAR on La Palma over 28 nights distributed over several months in 2014 and 2015. The shaded region shows the interquartile range of the data.

3. STEREO-SCIDAR PROFILES

Stereo-SCIDAR was operated on the 2.5 m Isaac Newton Telescope (INT) for a total of 32 nights over two summers in 2014 and 2015.[8] Figure 3 shows the median profile from all of the data. The figure also shows the inter-quartile range. This is an important parameter to be considered along with the median profile itself. The median profile shows an inclination for prevalent layers at certain altitudes. This is not seen in previously published data,[9] but here the data is limited to summer months. The median profile also shows a thin surface layer which is nearly three orders of magnitude stronger than the higher layers. The inter-quartile range shows that at lower altitudes (<10 km) there is often no turbulence strength, but that there are two layers at ∼12 km and ∼14 km which are often present.

Figures 4, 5 and 6 show some example profiles from the Stereo-SCIDAR instrument on the INT. The examples were chosen to show a sample of the different profiles. It can be seen that the atmospheric turbulence does appear in layers, which can change in altitude and strength over short and long time scales. They are presented here to give an example of the varying profiles that are encountered at this site.

4. APPLICATIONS FOR EXTERNAL ATMOSPHERIC PROFILING

Estimating the atmospheric turbulence profiles directly from the AO wavefront sensor telemetry is an extremely useful technique, providing valid and valuable profiles. However, external profiles can provide profiles when the AO system is not on-target and is un-biased, i.e. it is external to the telescope and the instrument and is therefore an independent measurement of the atmosphere. Here, we present some arguments as to why an external profiler might be beneficial.

- Instrument design and development
  Modern sophisticated instrumentation must be designed for the conditions in which it will be expected to perform. In order to assure scientific goals are met detailed simulations, including the turbulence profile, are required.
- Calibration and configuration of atmospheric parameter forecasting
  Forecasting is a powerful technique which enables atmospheric conditions to be estimated ahead of time. These models need to be calibrated and configured using on-site measurements.
- Queue scheduling
  By understanding the atmospheric dynamics it is possible to make sure the best instrument / science case is operational at the optimal time.

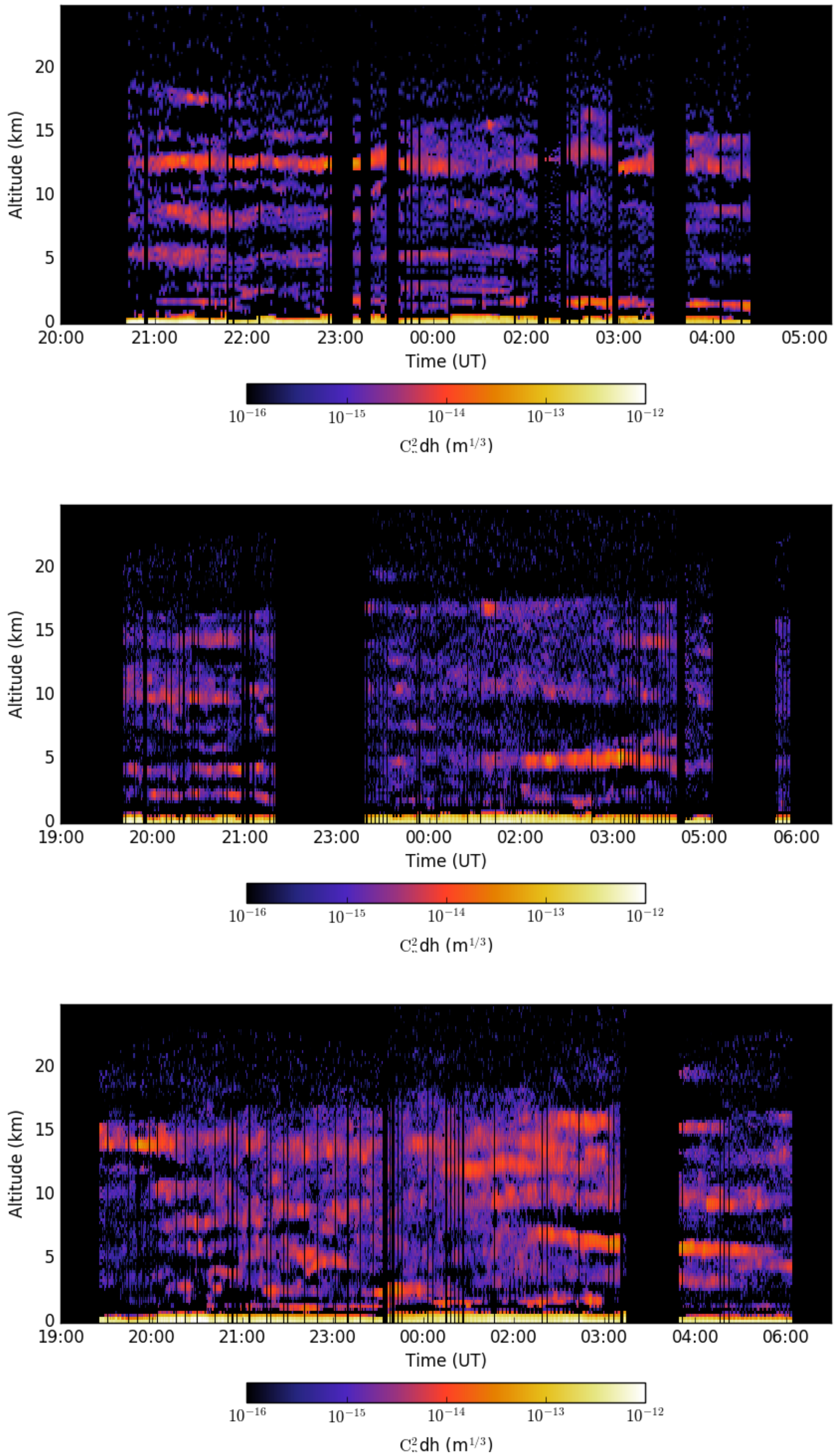

Figure 4. Example profiles from Stereo-SCIDAR on the INT, La Palma, from 16/07/2014, 7/10/2014 and 9/10/2014.

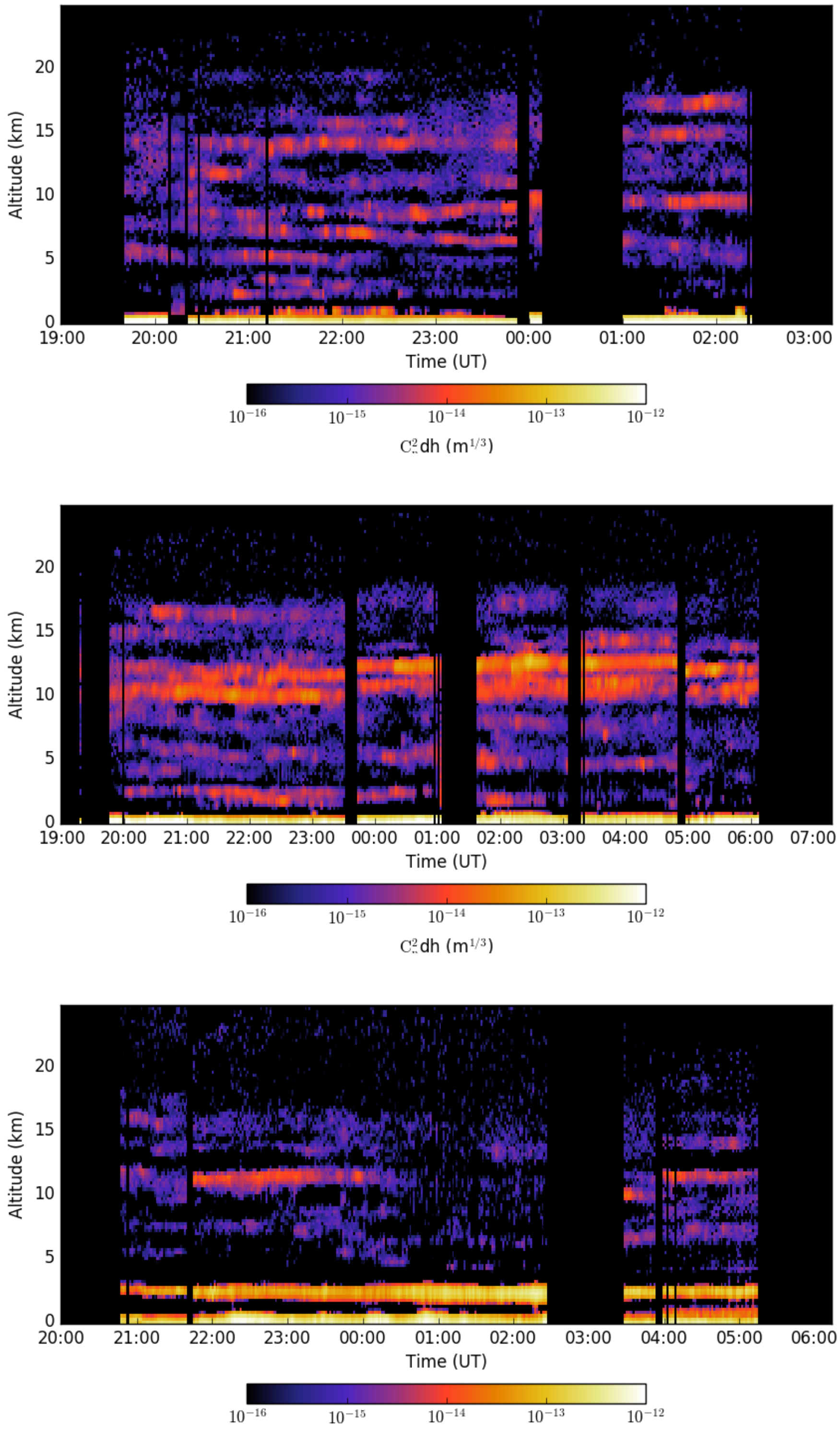

Figure 5. Example profiles from Stereo-SCIDAR on the INT, La Palma from 11/10/2014, 12/10/2014 and 29/06/2015.

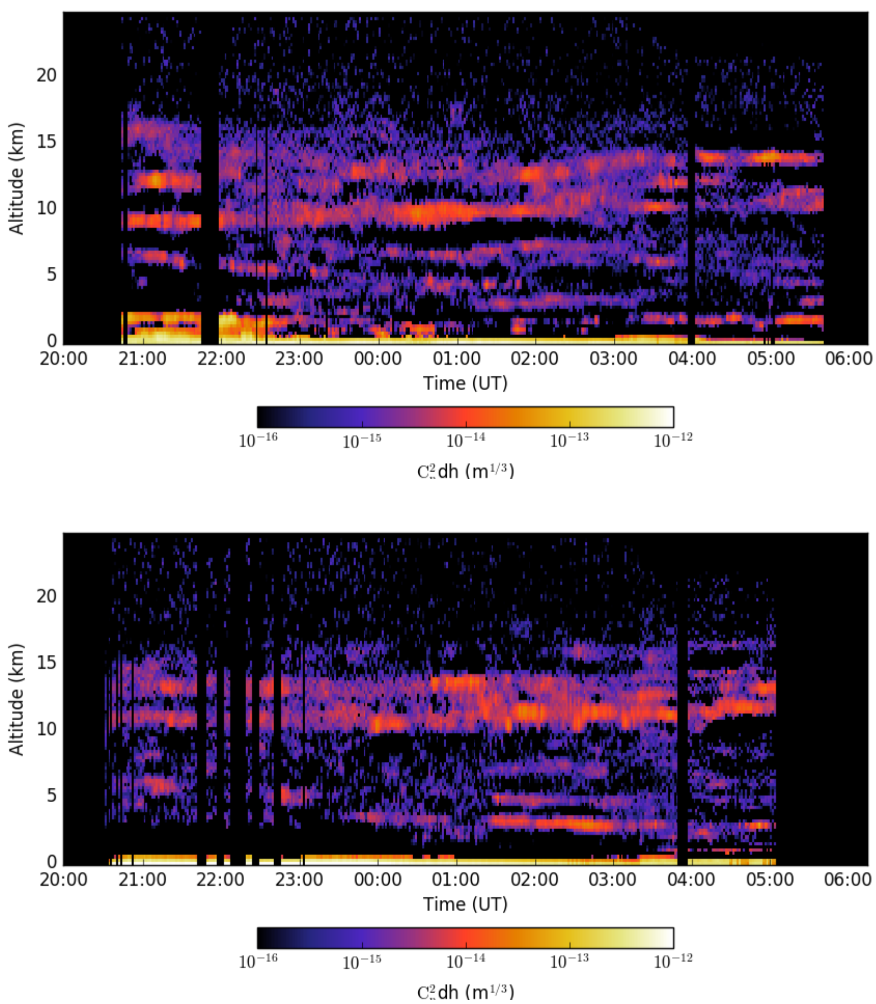

Figure 6. Example profiles from Stereo-SCIDAR on the INT, La Palma, from 30/06/2015 and 1/07/2015.

- Reconstructor pre-computation
  An external profiler can provide detailed and accurate concurrent turbulence profiles which can be used to generate the AO reconstructor before the instrument is on-target. This will save time and increase observing efficiency.

- Predictive AO correction
  Wind velocity profiles enable temporal control techniques, such as LQG, increasing the performance of AO systems.

- AO performance optimisation
  An un-biased (external) estimate of the optical turbulence profile will enable the instrument performance to be compared with models and optimisation procedures developed.

- Performance monitoring
  By comparing the performance of an instrument with the un-biased external profiler it is possible to identify performance issues which may not be possible if relying on the instrument itself for turbulence monitoring.

- Instrument comparisons
  An external profiler is the only method to supply an un-biased estimate of the current atmospheric conditions. It is therefore the only benchmark that can be used to compare performance and share optimisations from different instruments.

- PSF reconstruction
  Many PSF reconstruction algorithms rely on atmospheric parameters. External profilers provide an un-biased measurement and are specifically designed for the task. AO systems are not designed to return a precise turbulence profile.

- Automation
  Tomographic reconstructors are currently crafted by hand from turbulence profiles derived from AO telemetry. An external measure of the turbulence profile can provide an automated comparison of the AO reconstructor, providing a robust check of automated reconstructor generation.

- Dome-seeing and structure induced turbulence
  External profilers and internal dome seeing monitors can be used to measure and characterise dome turbulence. Ultimately, this information can be used to minimise dome turbulence though new isolation procedures both internal to the dome and of the dome itself.

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REFERENCES

[1] Cortes, A., Neichel, B., Guesalaga, A., Osborn, J., Rigaut, F., and Guzman, D., "Atmospheric turbulence profiling using multiple laser star wavefront sensors," *Monthly Notices of the Royal Astronomical Society* **427**(3), 2089–2099 (2012).

[2] Shepherd, H., Osborn, J., Wilson, R., Butterley, T., Avila, R., Dhillon, V., and Morris, T., "Stereo-scidar: High altitude-resolution optical turbulence profiling using a modified scidar instrument," *MNRAS* **437**(4), 3568–3577 (2013).

[3] Osborn, J., Wilson, R., Shepherd, H., Butterley, T., Dhillon, V., and Avila, R., "Stereo scidar: Profiling atmospheric optical turbulence with improved altitude resolution," in [*Proceedings of the Third AO4ELT Conference*], Esposito, S. and Fini, L., eds., INAF - Osservatorio Astrofisico di Arcetri (2013).

[4] Vernin, J. and Roddier, F., "Experimental determination of two-dimensional spatiotemporal power spectra of stellar light scintillation evidence for a multilayer structure of the air turbulence in the upper troposphere," *Journal of the Optical Society of America* **63**(3), 270 (1973).

[5] Fuchs, A., Tallon, M., and Vernin, J., "Focusing on a turbulent layer: Principle of the generalized scidar," *Publications of the Astronomical Society of the Pacific* **110**(743), 86–91 (1998).

[6] Osborn, J., Butterley, T., Föhring, D., and Wilson, R., "Characterising atmospheric optical turbulence using stereo-scidar," *Journal of Physics: Conference Series* **595**(1) (2015).

[7] Osborn, J., Butterley, T., Townson, M. J., Reeves, A. P., Morris, T. J., and Wilson, R. W., "Wind and turbulence velocity profiling for high sensitivity and vertical-resolution optical turbulence profiling with Stereo-SCIDAR," *MNRAS* (in preparation).

[8] Osborn, J., Butterley, T., Morris, T. J., and Wilson, R. W., "Stereo-SCIDAR optical turbulence characterisation from La Palma," *MNRAS* (in preparation).

[9] García-Lorenzo, B. and Fuensalida, J., "Atmospheric optical turbulence at the roque de los muchachos observatory: data base and recalibration of the generalized scidar data," *MNRAS* **416**(3), 2123–2129 (2011).