Cute-SCIDAR at Paranal for E-ELT Site Characterisation

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A new version of the cute-SCIDAR instrument, which employs the generalised SCIntillation Detection And Ranging technique to obtain detailed atmospheric turbulence profiles with height, has been designed, developed and tested by the Instituto de Astrofísica de Canarias. The instrument was developed to match the requirements of the ESO VLT Auxiliary Telescopes, within the framework of the European Extremely Large Telescope site characterisation project. Commissioning at Paranal was successfully carried out in November 2007. This upgraded version of the original instrument, presently working at the Roque de los Muchachos Observatory, allows g-SCIDAR turbulence profiles to be obtained in real time, a novel achievement in site testing and also a crucial tool for the optimum design and operation of Adaptative Optics and Multi-Conjugate Adaptive Optics systems.

The SCIDAR technique

SCIDAR, SCIntillation Detection And Ranging, has proved to be the most efficient and reliable technique to accurately measure the optical vertical structure of the atmospheric turbulence strength from ground level. The concept (Vernin & Roddier, 1973) and technique come from the original one developed since the 80's by Jean Vernin, Max Azouit and collaborators at Nice University (Vernin & Azouit, 1983; Vernin & Muñoz-Tuñón, 1992). The method consists of the acquisition of a large number of images with very short exposure time (typically from 1 to 3 ms, depending on the object and the desired signal-to-noise ratio) of scintillation patterns produced by a double star. The average autocorrelation function computed from these images shows a linear sequence of peaks corresponding to the different turbulent layers. The distance between each peak and the centre gives information on the height of the turbulent layer (see example in Figure 1).

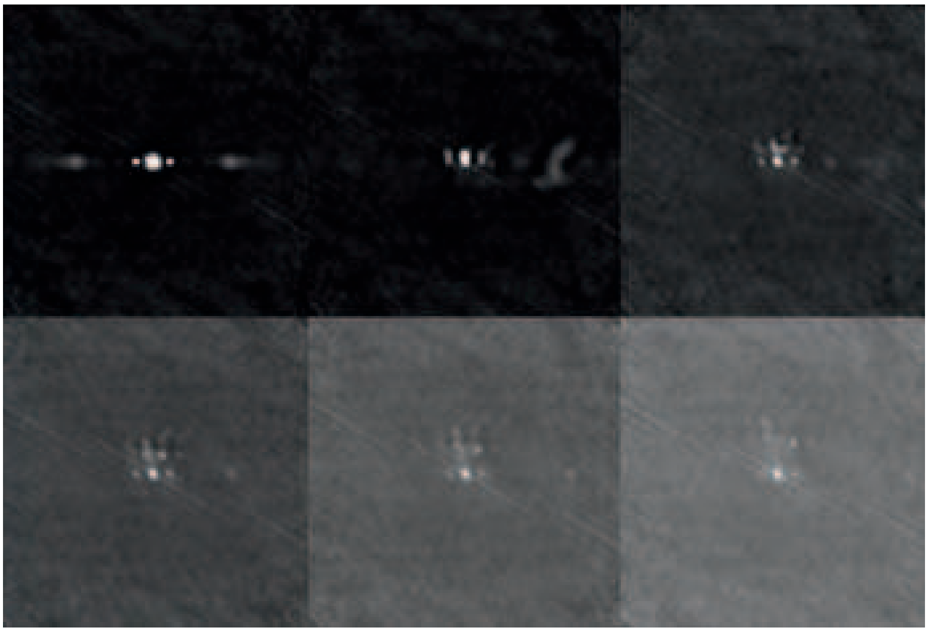

Figure 1. Top left: Normalised autocorrelation of a series of scintillation pattern images of a binary star; two turbulent layers can be distinguished clearly. From the 2D autocorrelation, the structure constant of the refractive index with height, $C_n^2(h)$, can be derived. The second to the sixth frames (left to right, top to bottom) show the cross-correlations between two scintillation pattern images: cross-correlations between an image and the ensuing correlation image (upper centre), the second consecutive image (upper right), and so on (bottom row). From these 2D cross-correlations, wind velocity, V(h), can be inferred.

Initially, the *classical* SCIDAR was unable to sample the layers closest to the ground. However a smart modification of the technique (Fuchs, Tallon & Vernin, 1998) consisted in placing the analysis plane not in the pupil plane but in a conjugated plane located a few km below the former. This development thus allowed the measurement of the turbulence intensity from ground to about 25 km height. This version of SCIDAR is known as generalised-SCIDAR (g-SCIDAR).

In practice, the implementation of such a technique requires a minimum telescope diameter of approximately 1 m. So, performing routine measurements using g-SCIDAR at a particular observatory requires the use of significant resources. However, g-SCIDAR provides extremely valuable information regarding the optical atmospheric turbulence, in particular the knowledge of $C_n^2(h)$ (the structure constant of the atmospheric refractive index with height) and the wind profile (horizontal velocity of the layers) with a vertical resolution better than 500 m. Many essential parameters such as seeing (ε), Fried's parameter (r_0), coherence lengths and time of the wave fronts, isoplanatic angles (θ_0), etc. can be computed from g-SCIDAR data. The wind speed and direction with height V(h) can be retrieved by analysing the 2D cross-correlation functions from consecutive mean normalised images (see Figure 1).

Cute-SCIDAR since 2002 at the Canary Islands

Since 2002 campaigns have been carried out by the IAC staff (Fuensalida et al., 2004a; Fuensalida et al., 2004b, Fuensalida et al., 2007) at their observatories: the Observatorio del Teide (OT) on Tenerife island and the Observatorio del Roque de los Muchachos (ORM) on La Palma island, both in the Canary Islands. In order to perform routine observations, two g-SCIDAR instruments were designed and manufactured to fit the particular specifications of the telescopes which had to house them. They were Telescopio Carlos Sánchez (TCS) at the OT with 1.5 m diameter, and the Jacobus Kapteyn Telescope (JKT) belonging to the Isaac Newton Group of Telescopes at the ORM with 1 m aperture. Both systems implement the g-SCIDAR technique and include remote operation with facilities for conjugated plane positioning, spatial (X, Y) positioning (centreing), a rotating system to adjust the direction of the pixel grid to the observed binary axis, etc. The remotely operated instrument is called cute-SCIDAR (c-SCIDAR).

The high resource cost entailed by the monitoring of the turbulence with quite high resolution justifies the development of an instrument with few constraints. The plans for a long campaign of measurements of the vertical structure of the turbulence in the ORM and OT observatories has encouraged us to build an instrument with high performance and minimal operational overheads. With this experience, we have been able to develop a new version for the Paranal Observatory, within the European Extremely Large Telescope Design Study (Contract 011863 with the European Commission) which was supported by the European Community (Framework Programme 6, E-ELT Design Study).

C-SCIDAR at the Paranal Observatory

The c-SCIDAR/Paranal is a fully automatic instrument. This means a complete automation of both displacement of optical elements and rotation of the instrument itself. These movements are controlled by a user-friendly interface (Figure 2). Moreover, a custom-made software package performs fast data acquisition and processing, which can provide the turbulence profiles in real time, with and without the turbulence contribution of the dome. As a consequence, alignment and observation procedures are facilitated with minimal effort in the dome. The instrument, based in the original g-SCIDAR concept of the Nice University, was conceived to work in the coudé focus of one of the 1.8-m Auxilliary Telescopes (ATs) of the VLT. The coudé focus is available in the focal station through the Upper Relay Optics Structure (UROS), which becomes the interface between the AT and c-SCIDAR (see Figure 3).

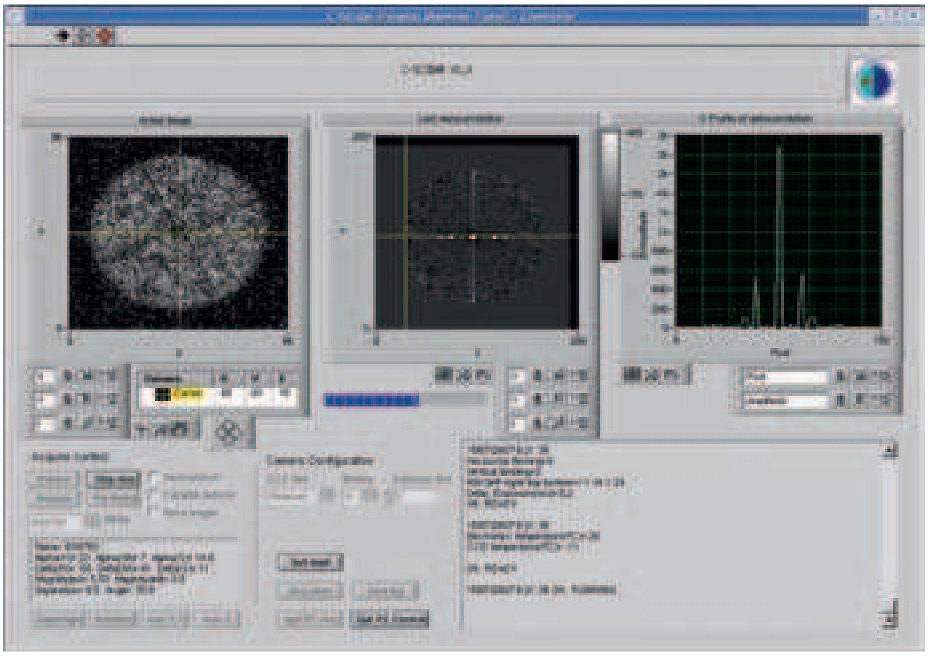

Figure 2. Snapshot of the c-SCIDAR/Paranal GUI. The image on the left shows the scintillation pattern of a binary star. The normalised autocorrelation function can be seen in the middle frame, while the right panel shows a cut of the autocorrelation along the binary axis.

The main features of c-SCIDAR/Paranal can be summarised as follows:

– Mechanical and electronic matching to the UROS/AT interface.
– The instrument has its own cooling system.
– Power supplies of the different systems are remotely controlled.
– Operation and data acquisition is fully remote by means of a user-friendly Graphical User Interface (GUI).
– Reduction of raw data is performed at a rate that is higher than that of the

Figure 3. Left: The cute-SCIDAR/Paranal attached to the AT4 crane, during the November 2007 commissioning. Upper: The original mechanical design of the instrument.

observations, so allowing the profiling of the optical vertical turbulence in real time (see Figure 4).

These design features lead to a high temporal efficiency during the observing campaign as well as providing an essential tool in order to optimise the efficiency of Adaptive Optics (AO) and Multi-Conjugate Adaptive Optics (MCAO) systems.

Regarding the c-SCIDAR mechanisms, the camera is attached to three movable stages which allow its movement along X, Y and Z directions. The Z axis is employed both to determine the position of the pupil plane and the focus (a single star allows the state of collimation of the beam to be easily verified), but is mainly used to fix the conjugated plane where the observations will take place. The X and Y direction stages are devoted to the centring of the camera in the XY plane, correcting small displacements in the observation plane produced by flexure. The maximum range in the X and Y directions is 25 mm, whilst in Z it is 100 mm. An iris mechanism – an adjustable aperture diaphragm placed in the focal plane – facilitates the centring of the pupil image of the double star onto the camera field of view; the M6 mirror of the AT also plays an important role in this particular procedure. Finally, a rotator mechanism allows the rotation of the instrument as a whole in a range from 0° to 270°, thus permitting the orientation of the binary star axis with the array of the CCD camera.

All the observations and data analysis procedures applied to this upgraded version are the result of the development work carried out during the last few years by the IAC with the previous instruments at the Canaries Observatories. ESO will now operate the Paranal instrument and take care of the measurements while the IAC SCIDAR team will continue collaborating with ESO, within the FP6 Site Characterisation WP, on the data validation and analysis.

Present status

Cute-SCIDAR/Paranal was successfully commissioned during November 2007 by the IAC team with the collaboration of the Paranal staff. In principle, regular long runs were planned to be performed for the duration of the FP6 contract. Actually they took place just after the commissioning period during a week in November and later, during 10 nights in December. No new campaigns have been carried out since then due to the lack of a free UROS (since the one initially devoted to SCIDAR was re-assigned to PRIMA).

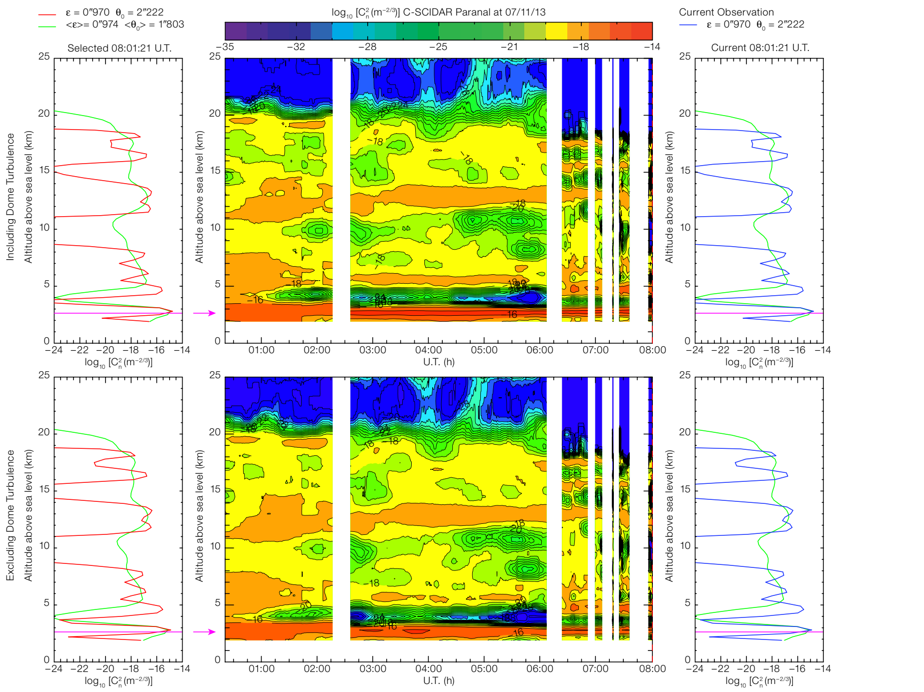

Figure 4. Output in real time of the profiles during an actual observing night. The central part is a representation of C_n^2(h). The contour plots are updated in real time during the observation. The upper contours represent turbulence intensity with dome seeing included, while the lower panel shows the same but excluding dome turbulence (the white vertical gaps are associated with a change of object). The left and right columns of the panel show individual vertical profiles: green is the average profile, navy corresponds to the last profile, and red to the particular profile chosen with the cursor.

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Figure 5. Picture taken at the moment when cute-SCIDAR/Paranal was providing real-time profiles for the first time during the scientific commissioning in November 2007.