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Single detector stereo-SCIDAR at the 2.3 m Telescope at Siding Spring Observatory

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ABSTRACT

Site characterisation for atmospheric turbulence analysis is crucial for the development and design of adaptive optics systems, especially for systems for extremely large telescopes. There are many seeing monitors and optical turbulence profilers. Seeing monitors such as the Differential Imaging Motion Monitor (DIMM) often have a simpler design and smaller telescope requirements than optical turbulence profilers at the expense of height resolution limitations and are only able to provide seeing measurements integrated over the entire atmosphere above the instrument, but cannot provide a detailed height resolved atmospheric turbulence profile. Other more complex instruments such as the Multi-Aperture Scintillation Sensor (MASS), Slope Detection and Ranging (SLODAR) or generalised Scintillation Detection and Ranging (SCIDAR) require larger telescope apertures and more complex setups, but can yield a more spatial and time resolved atmospheric turbulence profile. The generalised SCIDAR technique suffers from signal limitation due to its optically overlapping pupil images. This can be overcome with stereo-SCIDAR by separating the pupil images optically making the opto-electronic setup more complex and expensive as two scientific cameras are required to record the optically separated pupil images. Furthermore, as site testing campaigns are expensive to run at large telescopes, there are few campaigns that have been conducted frequently for an extended period of time to reliably investigate detailed seasonal changes. To overcome some of these challenges, the Advanced Instrumentation and Technology Centre of the Research School of Astronomy and Astrophysics at the Australian National University has designed, built and operated a single-detector generalised stereo-SCIDAR. The instrument was commissioned on the 2.3 m Telescope at Siding Spring Observatory in April 2022 and has been operated every month for a year. In this paper, we present the design of the single-detector generalised stereo-SCIDAR instrument as well as the preliminary results of data evaluation focussing around the system's capabilities and the seasonal changes of the atmospheric turbulence patterns at Siding Spring to showcase its potential for site characterisation at other astronomical sites in the world.

Keywords: Stereo-SCIDAR; site characterisation; site testing; atmospheric turbulence

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1. INTRODUCTION

A generalised SCIntillation Detection And Ranging (SCIDAR) instrument [3] is a turbulence profiler that is known for resolving atmospheric turbulent layers at high spatial resolution and for its ability to also identify wind speeds and directions not only spatially resolved but also over time. The technique cross-correlates the scintillation patterns of a double star at the telescope pupil to derive the profile. Recent generalised SCIDAR instrument developments expand to the generalised stereo-SCIDAR, which separates the traditionally overlapping pupil images fully and re-images them onto two [4] or even a single detector [2]. The Advanced Instrumentation and Technology Centre (AITC) of the Research School of Astronomy and Astrophysics (RSAA) has developed and built a single detector, generalised SCIDAR instrument with a compact design. The instrument was commissioned at the 2.3 m telescope at Siding Spring Observatory (SSO) and has been operated over a year for a seasonal turbulence profile campaign. After outlining the aim of the system in section 2, an overview of the method is given in section 3 including the optical design of the instrument, the measurement campaign, and the data recordings. Section 4 briefly discusses first, preliminary results before the work to date is summarised and an outlook for future works is provided in section 5.

2. AIM

The aim of the project is to showcase the special compact optical design and identify the limits of the single detector, generalised stereo-SCIDAR operated at the 2.3 m Telescope at Siding Spring Observatory, Australia. Furthermore, as data was taken over a year, the campaign provides a great opportunity to compare the results with existing models over all four seasons at a site that is a renown Australian astronomical site, but not situated in such a high altitude and therefore not as well modelled and characterised as world-class high-altitude observatories and future extremely large telescope sites.

3. METHOD

3.1 The Instrument

A schematic of the single detector, generalised stereo SCIDAR instrument is shown in Figure 1. After the light has been collected by the telescope and is divided by a dichroic beam splitter that feeds a guiding camera (not shown in the diagram), the lights passes through a lens system that has a roof prism positioned at the focus. Here the light from the double stars is separated, so that the two star scintillation pupil images are reimaged fully separated on the detector.

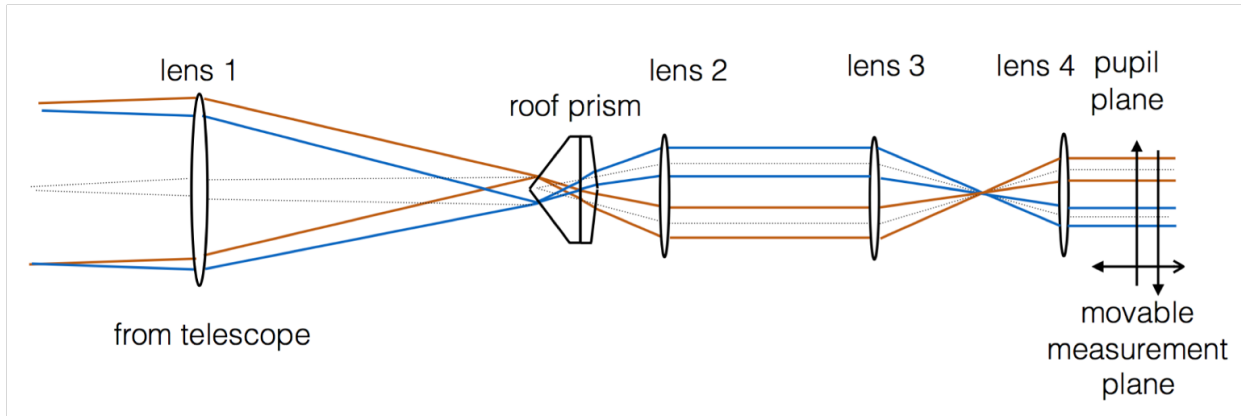


Figure 1. Schematic of the single detector, generalised stereo-SCIDAR optical design [2]: the light from the double stars, depicted here in red and blue, passes through a lens system with the roof prism positioned at the focus. The pupil images are then fully separated on the detector.

3.2 Measurement Campaign

The instrument was commissioned in April 2022 and has been in operation for over a year until June 2023. With the exception of September 2022, the instrument was operated a few nights every month. Quite a lot of nights were lost due to bad weather and not every night was very clear when data was recorded. Figure 2 shows the number of scheduled nights that were lost due to bad weather (red), nights with low quality data due to bad conditions (dark brown) and good nights (yellow).

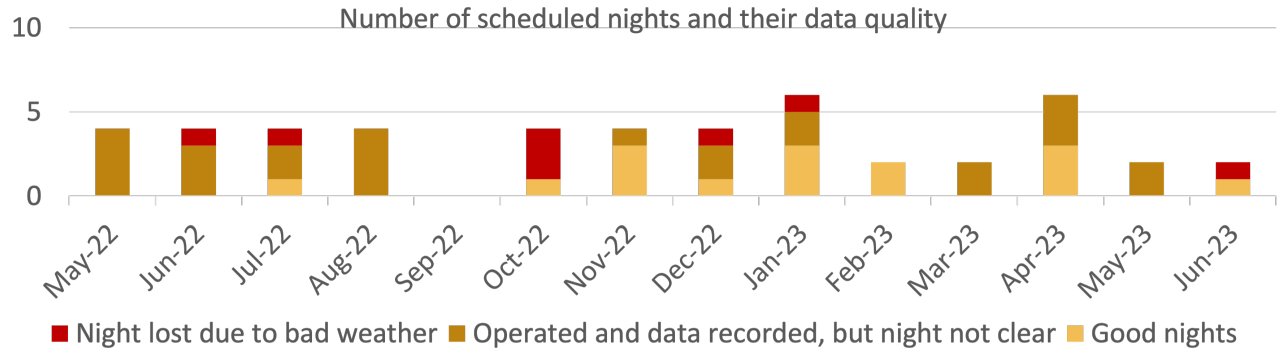


Figure 2. Overview of scheduled nights for SCIDAR operation during the ongoing campaign; red: no data recording due to poor weather; dark brown: recorded data available, but night was partially or intermittently cloudy; yellow: generally good night with plenty of data taken.

3.3 Data Recordings

Weather permitting, datasets for a duration of 300, 600 and 900 seconds were taken at a frame rate of 300 frames per second and 530kB/frame. Breaks of similar length were made between recordings to manage the size of the recording and the amount of created data. Good nights will have up to 30 recordings of 600 seconds each. Bad nights may only have a handful of recordings at 300 seconds each. When analysed, each frame gets reduced to around a quarter of its file size while the pupil image are cropped as shown in Figure 3.

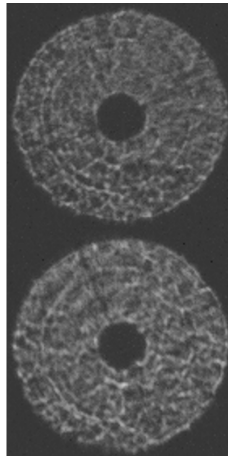


Figure 3. Example image of a reduced pupil image

4. PRELIMINARY RESULTS

After pupil cropping (see Figure 3), the pupil images are cross-correlated and the C_n^2 profile is derived. Figure 4 shows a dataset analysis over 900 seconds from 19 June 2022 recorded at 19:21. Figure 5 shows a dataset analysis over 600 seconds from 14. January 2023 recorded at 23:38. The frames of each recording are grouped in batches of 10000 frames each, for which a C_n^2 profile is calculated. Their average profile is shown in the figures. The profiles all follow a general pattern of a strong ground layer with decreasing turbulence over increasing altitude. The January recording does not show so strong, distinct layers in lower altitudes as the June data.

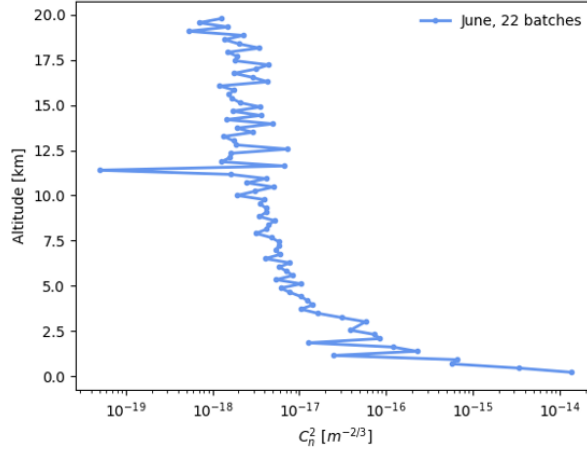


Figure 4. C_n^2 profile of 220,000 frames batched in 22 groups of 10,000 images each for a dataset from 19 June 2022 at 19:21

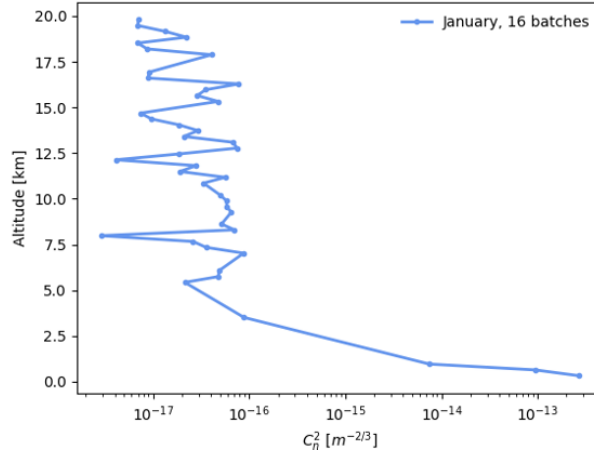


Figure 5. C_n^2 profile of 160,000 frames batched 16 groups of 10,000 images each for a dataset from 14 January 2023 at 23:38

5. CONCLUSION AND FUTURE WORK

A single detector, generalised stereo-SCIDAR was developed at the AITC, commissioned at the 2.3 m Telescope at SSO and has been in monthly operation since. While data analysis has not finished, preliminary results are promising and the data analysis will soon be expanded to not only the C_n^2 profile, but also wind speed, wind direction and a dynamic temporal analysis over the duration of the recordings to investigate turbulence differences over the course of the night. A seasonal analysis will also be included and a comparison with existing turbulence models is envisioned. Furthermore, a small, low cost turbulence profiler called Ring-Image Next Generation

Scintillation Sensor (RINGSS) [1] has been available for some nights during the measurement campaigns in January 2023 and April 2023 during which turbulence data was recorded at the same time, in the same location and in the same direction of the night sky. Hence, comparison of the data taken by both sensors will be undertaken and further, simultaneous observation campaigns are envisioned for 2024.

ACKNOWLEDGMENTS

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