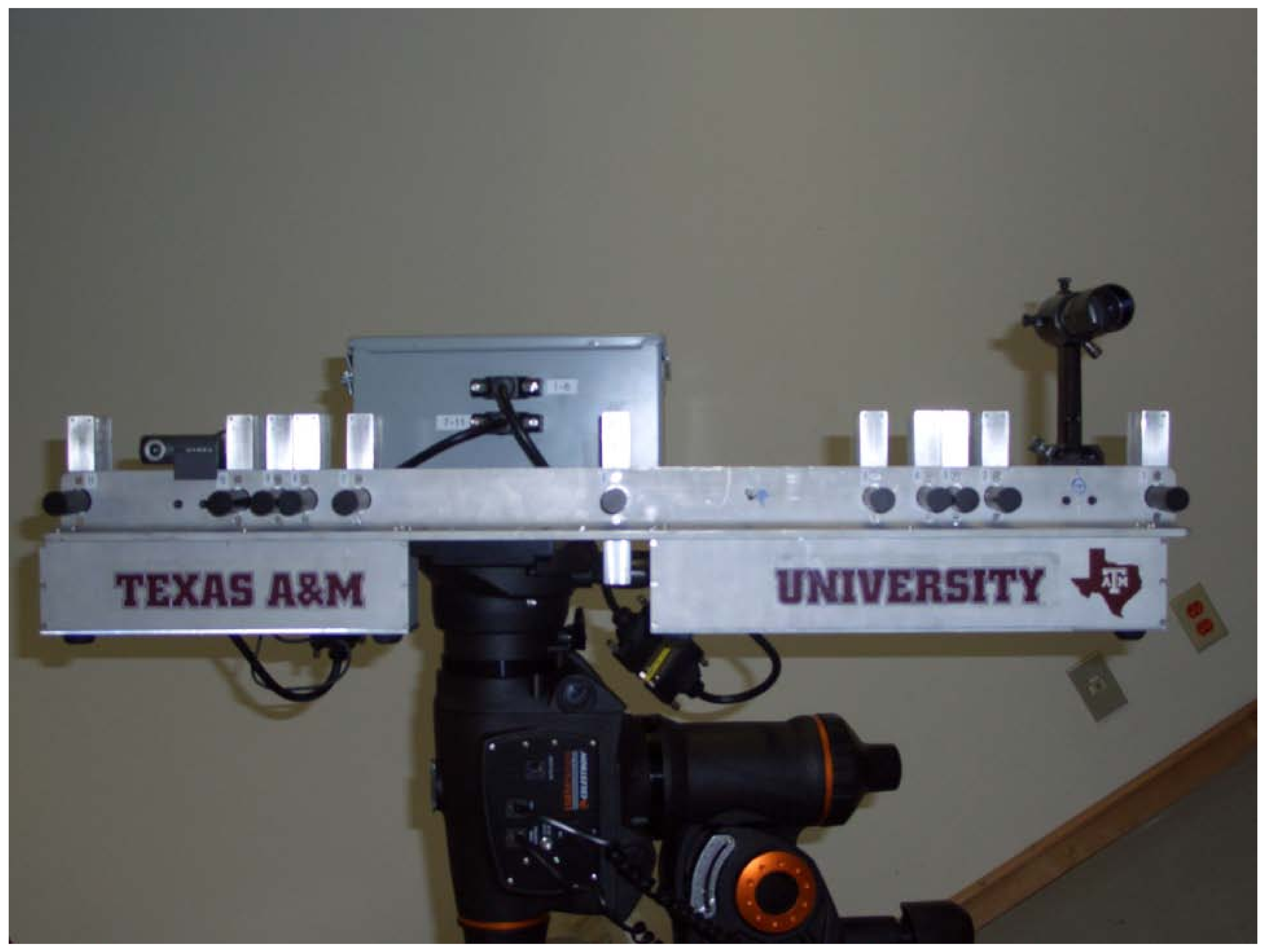
MooSci: A Lunar Scintillometer

S. Villanueva Jr.[1], D.L. DePoy[1], J. Marshall[1], A. Berdja[2], J.P. Rheault[1], G. Prieto[2], R. Allen[1], D. Carona[1]

[1] Department of Physics and Astronomy, Texas A&M University, 4242 TAMU, College Station, TX, USA 77843-4242;

[2]GMTO/Las Campanas Observatory, Colina El Pino Casilla 601 La Serena, Chile



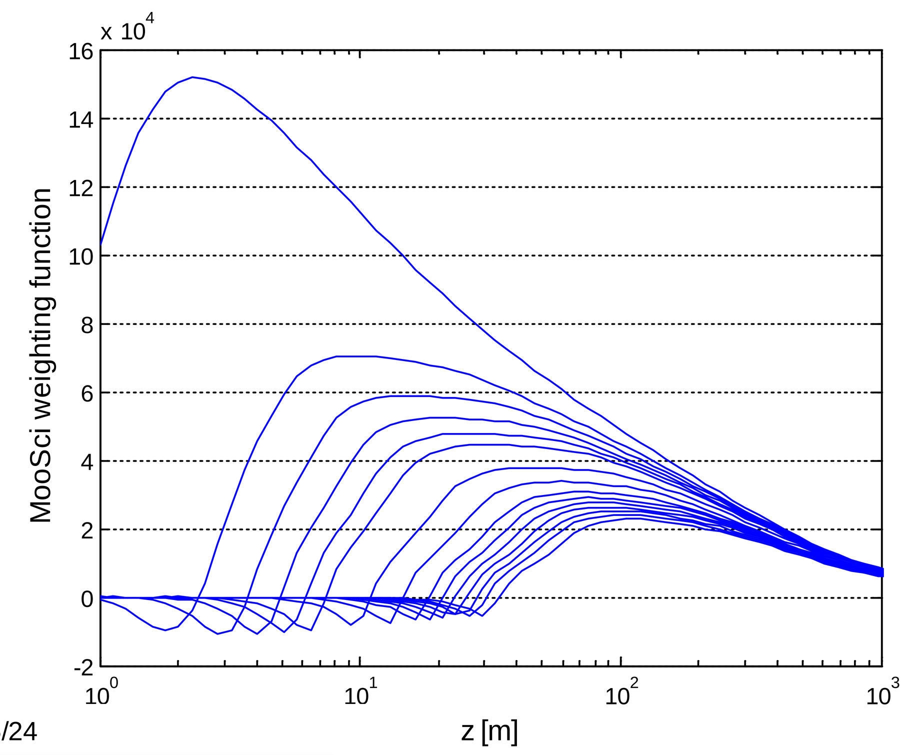
Scintillation

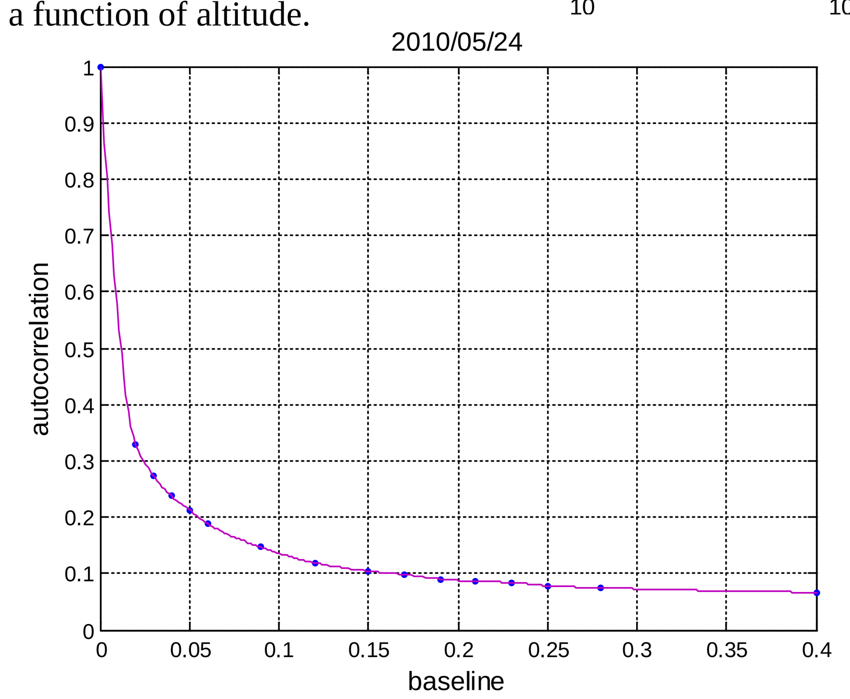
Scintillation, the twinkling of stars, is closely related to the turbulence profile of the atmosphere and the "seeing" of a telescope's site. Beckers proposed a linear array of photo detectors to measure the scintillation of the Sun. This idea was adapted by both Hickson & Lanzetta and Rajagopal & Tokovinin to use the Moon to measure lunar scintillation. Unlike the scintillation in the high atmosphere that causes stellar twinkling, the scintillation of extended objects is caused by turbulence in the lower atmosphere, making the technique potentially useful in determining the strength and prevalence of ground layer effects.

This paper describes an instrument that builds upon previous instruments and techniques to improve the data collection processes of measuring lunar scintillation. What we describe is the design of MooSci, an 11 channel lunar scintillometer.

Scintillation Model

Tatarskii developed the theory of light propagation through weak turbulence. Later studies by Hickson & Lanzetta and Tokovinin et al., developed new methods and models for adapting previous models to lunar scintillation. MooSci utilizes a model similar to Tokovinin's LuSci, that relates the covariance of the lunar signal (C_l) to the weighting function ($W(r,z)$) and the profiles of the atmosphere, where the is a measure of the relative strength of turbulence as a function of altitude.





The current model incorporates into the weighting function the Moon's phase, apparent diameter, local wind speed, and the angle of the Moon's terminator with respect to the baseline of MooSci's detectors. Reconstruction of the profile begins after the weighting functions and covariances of the individual baselines are calculated.

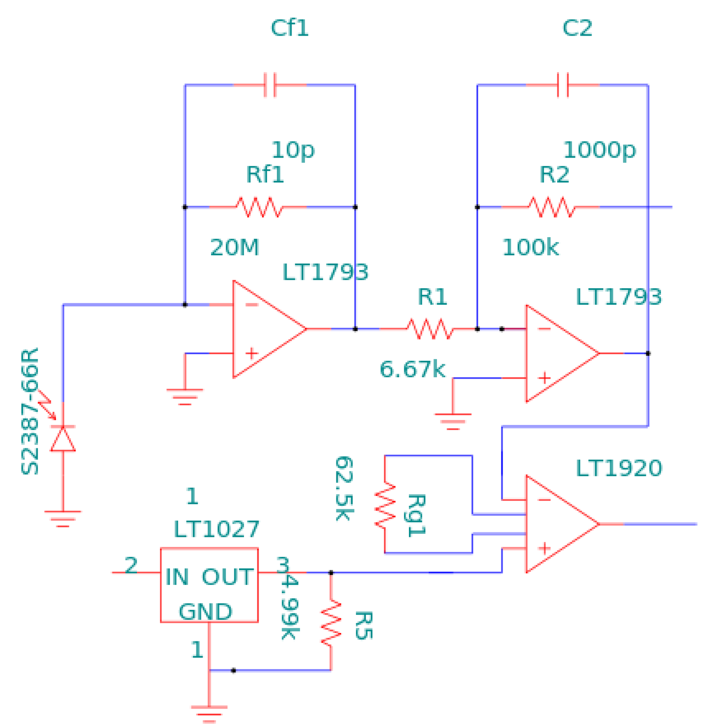
ABSTRACT

MooSci is a linear array of photodiodes that measures time varying intensities of light reflected from the Moon, lunar scintillation. The covariance between all possible pairs of photodiodes can be used to reconstruct the ground layer turbulence profile from the ground up to a maximum height roughly determined by the distance between the furthest pair of detectors. This technique of profile restoration will be used for site testing at various locations. This paper describes the design of a lunar scintillometer and preliminary results from Las Campanas Peak

Instrument Design

MooSci has been designed carefully to accurately measure lunar scintillation. Simple tests were performed on the optical systems the instrument, one to test for optical crosstalk, and one to test for phase shifts in the signal. If not accounted for, crosstalk can lead to overestimating the covariance, and phase shifts can underestimate the covariance. Below we describe the various aspects of the MooSci design in detail.

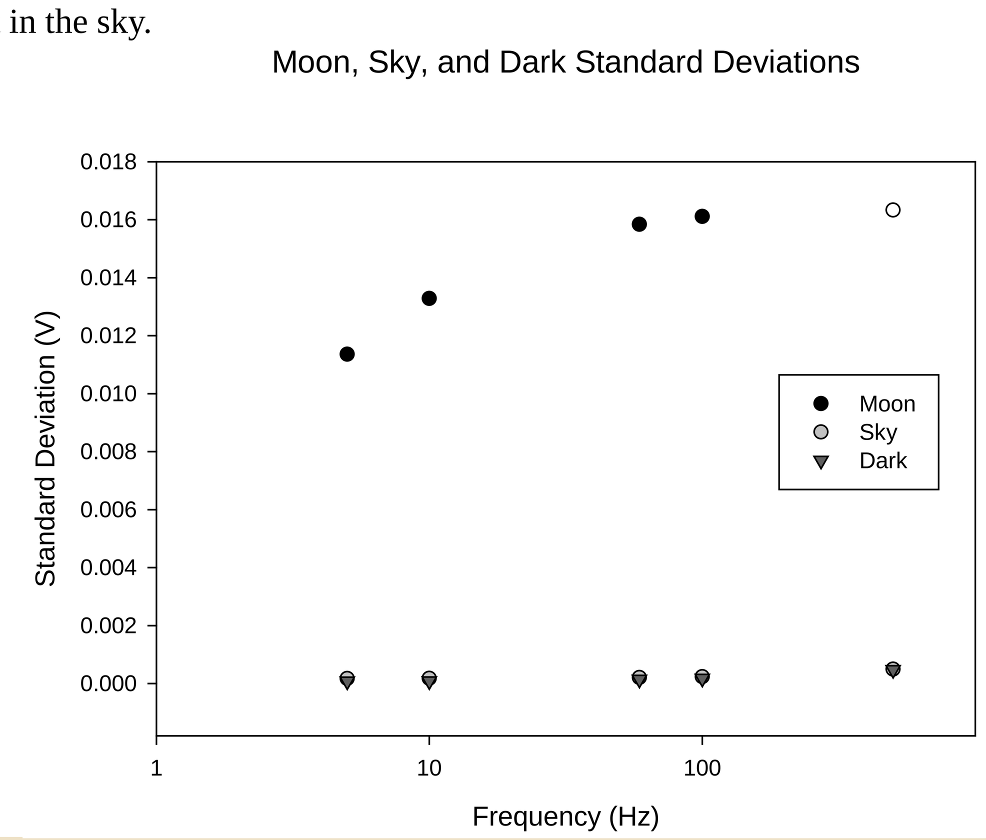
MooSci's field of view is set by the mechanical design rather than the optical components. A 5.8x5.8mm Hamamatsu S2387-66R photodiode sits 16mm below the bottom of two 25.4mm, 12.7mm diameter Thorlabs optical tubes. There are two retaining rings that hold a WG30530 3mm sapphire window 8mm below the edge of the tube. The window is used to protect the photodiode and components from the elements. The spacing allows room for the retaining rings and the lens cap that protects the electronics when the scintillometer is not in use. This gives the detector a 6° field of view and sets the requirement that our mount be able to track to within ±3° of the Moon.



One of the key challenges to the MooSci design is obtaining S/N > 10^4 at our band pass requirements. The band pass requirements are set by the rate at which lunar scintillation, occurs. In the case of lunar scintillation, this is at frequencies below 500Hz. This is accomplished by using the circuit to the left. Start with the current produced by the 5.8x5.8mm Hamamatsu S2387-66R photo diode and invert that into a voltage via an LT1793 op amp with a 20MΩ feedback resistor. This op amp will also have a 10pF capacitor in parallel that filters signals higher than ~800Hz. The output then feeds another LT1793 that inverts the signal and applies a gain of ~15. The second stage has another higher frequency filter set by the 100k resistor and the 1000pF capacitor at ~1.6kHz.

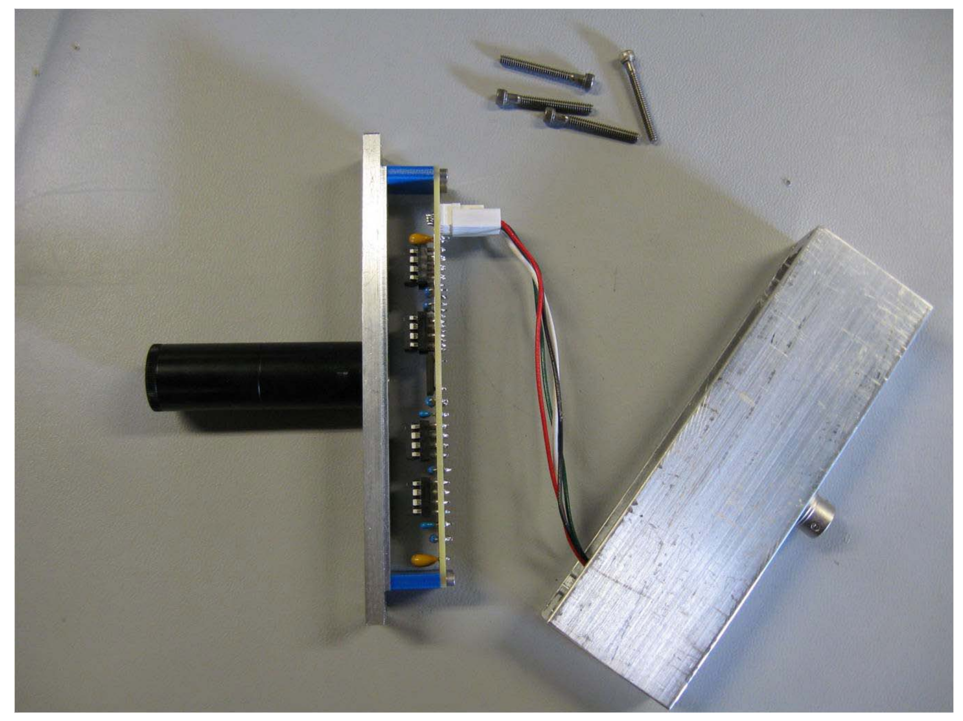
This signal is then fed into a LT1920 instrumentation amplifier. The signal is subtracted from a 5VDC signal and multiplied by another factor of 1.8. The 5VDC is provided by a LT1027 voltage regulator with a 4.99k resistor as a source to ground. The signal is centered between ±10VDC to allow for the optimal use of a 16-bit ADC that converts the analog voltage to a digital signal for subsequent processing. All components are operating from a ±15VDC power supply with 1μF tantalum capacitors tied to ground to filter out any voltage spikes or high frequency noise. The signals from the Moon are dependent on phase, position, and location. The most obvious and noticeable change in signal is due to the changing phases of the Moon. The signal increases as the Moon approaches full, and then decreases as it wanes. The position of the Moon in the sky also affects the signal, although not to the extent of the phases. The signal increases as the Moon approaches zenith, or is highest in the sky.

The location of the Moon also affects the signal values. When the Moon is at perigee it is brighter and larger than at apogee. This has effects both on signal and the model. These signals can range from 5-18V with a consistent 100Hz noise of only .18mV. This yields S/N ratios in the range from 2.8×10^4 when the Moon is low in the sky and out of phase, to S/N ratios of 10^5 when the Moon is full and at zenith. These S/N rations are adequate to measure the scintillation of the Moon.



Operations

A LabVIEW program collects the data from the ADC and writes files to the laptop containing the data and the MooSci controls. The LabVIEW interface also displays the average values and standard deviations of all 11 channels in ~5 second intervals and all 11 temporal voltages. The user also may view the power spectrum and temporal voltages for any two sequential channels, also updated every 5s. These displays are useful for monitoring the quality of the data during observations. The program has a simple layout that allows the user to take Moon, Sky, and Dark measurements. Each setting has preset flags on the average value and standard deviation that let the user know if they are taking data consistent with previous measurements. The LabVIEW program acquires 49,972 data points at a rate of 10kHz before updating the visual displays. The program then writes 20 of these intervals (~100s) to a single data file. Each sequentially numbered file has the location, time, date, and type of file (Moon/Sky/Dark) included. There is also a test mode that allows the software to acquire data but does not write any files. This is used for troubleshooting and various other tasks.

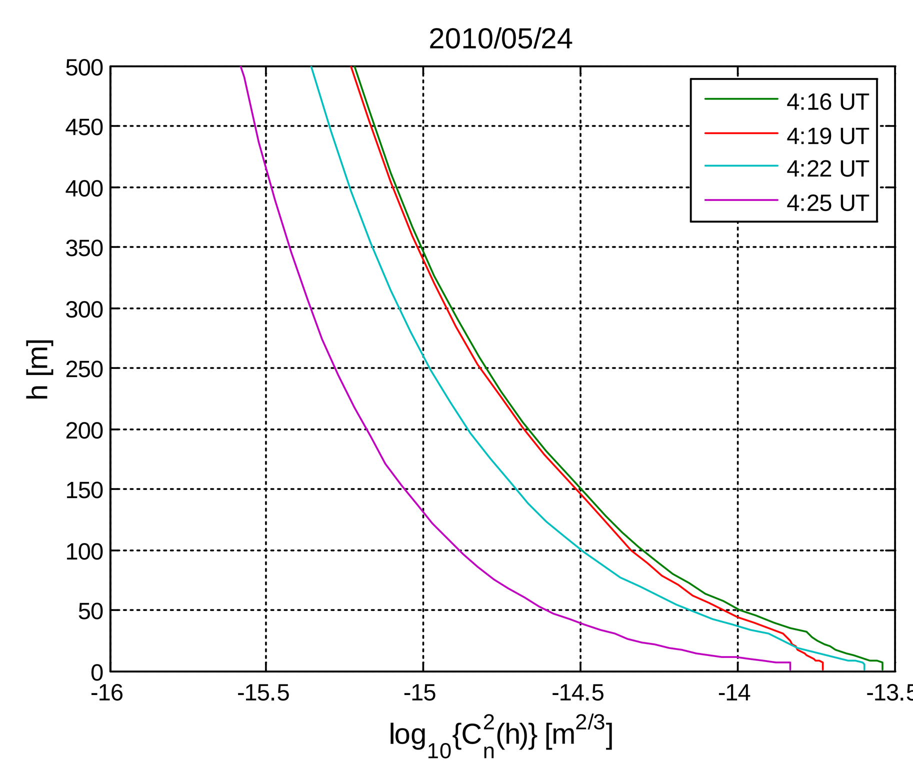


The laptop that operates MooSci is connected using a virtual network computing (VNC) connection that enables remote operations. All of the functionality of MooSci can be operated remotely. The webcam provides the user with real time video of the Moon. The web cam and remote mount control allow any problems with tracking to be addressed without the need to visit the instrument. Clouds or any other issues will clearly be displayed in the data stream.

Preliminary Results

The first step in reconstructing the turbulence profile is to ensure the data quality of the measurements. The individual intensity variations over the 11 detectors are documented with the time and location of acquisition. This information is very important to calculating the weighting function. First, the stability of the night's measurements is checked to avoid any corrupt data due to an unnoticed occultation by clouds or an error in tracking. Periodic Sky measurements are taken and the quality of the data is checked, although this is not a particular problem since the level of signal and the power spectrum shape can be directly observed by the user on the acquisition program interface during acquisition. The averaged power spectra from the Moon are also checked to avoid any parasitic reflections from adjacent structures and to check if any sources of contamination were present. From the selected data, the scintillation index variances and covariances are calculated. It is very important to note that the scintillation index on every channel should be calculated by the ratio of the intensity fluctuation and the difference of the average intensity of the Moon signal and the Sky signal. The availability of good Sky measurements allows for the efficient elimination of the individual offsets affecting the various detectors. From the times and location of the data, the scintillation index model is constructed. The air mass, Moon phase, the angle of the Moon's terminator relative to MooSci's baselines, and the Moon's apparent diameter are all calculated from this information. MooSci's experimental covariance is then introduced into the reconstruction software and the profiles are calculated as shown in the figure below. The baselines and procedures used to reconstruct the profile are the same as LuSci for comparison. Improvements and adaptation to MooSci's increased number of baselines and detectors will be soon to be introduced, and the results from Las Campanas peak will be presented in this manner in a forthcoming paper.

Future observations will also be supported by wind data and possibly sonic anemometers to test the occurrence of Kolmogorov or non-Kolmogorov cascade effects in the ground layer. This additional set of information will be integrated into the MooSci model for a better estimation of the turbulence profiles.



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