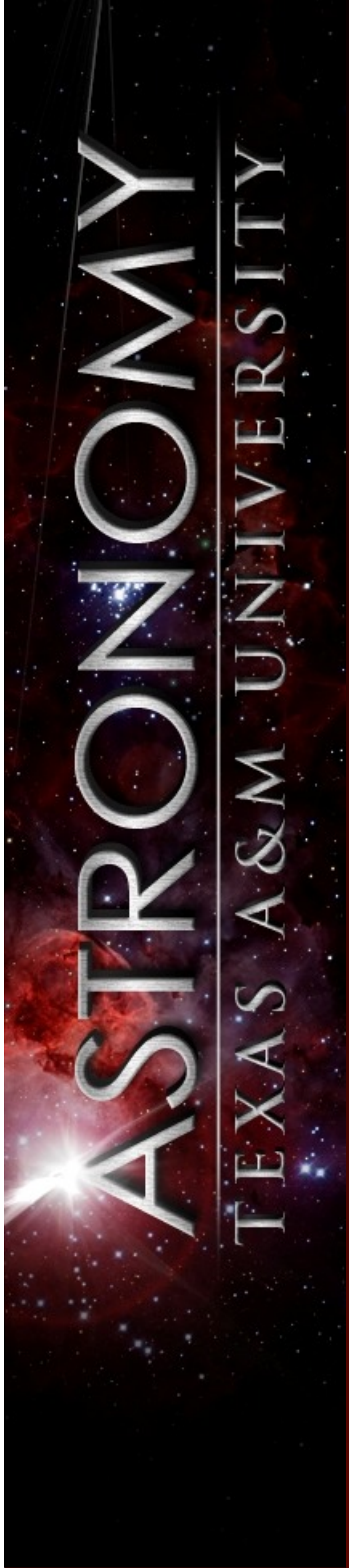

Design of the MooSci Lunar Scintillometer

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Introduction

Motion of light as it moves through turbulence in Earth's atmosphere, or "seeing", has long limited the achievable angular resolution of ground-based observatories. Understanding the turbulence profile of the atmosphere at a site can lead to smarter telescope construction and inform the development of AO systems. Turbulence can be understood by measuring the scintillation of a number of astronomical sources.

Stars - Stellar scintillometers are in use at many observatories today (i.e. MASS, Tokovinin 2007). Stellar scintillation is strongest in the upper atmosphere. Therefore, this technique does not probe the ground layer (<500m) turbulence where telescope design is a factor.

The Sun - Solar scintillometers (Beckers et al. 1997) detect high signal and are sensitive to the ground layer, but can only be used during the day when atmospheric conditions can very greatly from nighttime conditions.

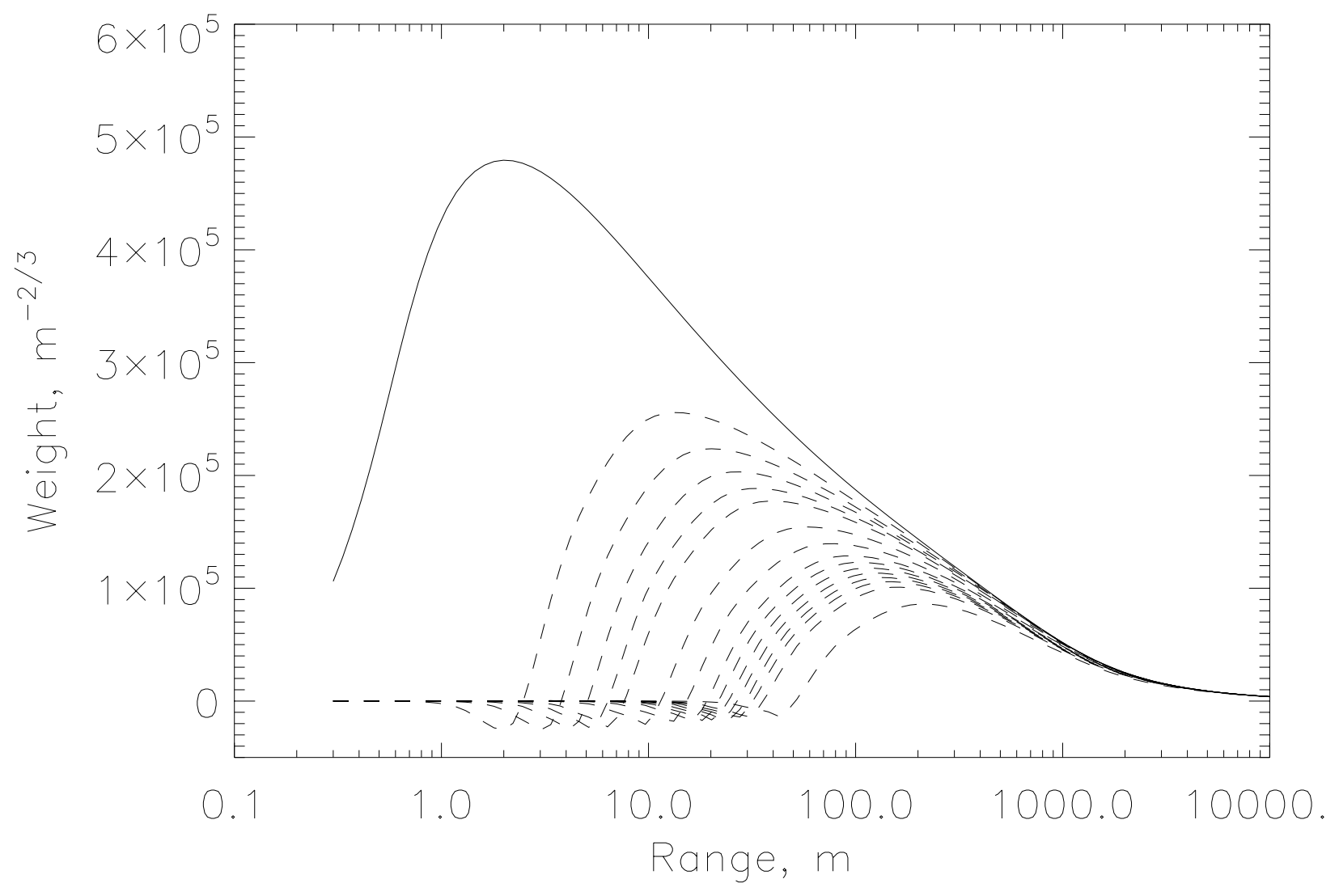
Planets - The planets are visible during the night and sensitive to the ground layer but provide very low signal.

Moon - The Moon provides adequate signal, is sensitive to the ground layer profile, and visible during the night. This makes it a good target for a ground layer scintillometer. Additional lunar scintillometers have been designed (Hickson & Lanzetta 2004) (Rajagopal et al. 2008) (Tokovinin et al. 2010).

Hickson & Lanzetta (2004) present a design for a linear array of detectors. Rajagopal et al. (2008) use a similar design for the LuSci instrument. MooSci expands upon the LuSci design. In this design the covariance between detectors can be used to calculate the strength of the turbulence profile by the following.

$$C_I(r) = \int_0^\infty W(r,z) C_n^2(z)\ dz$$

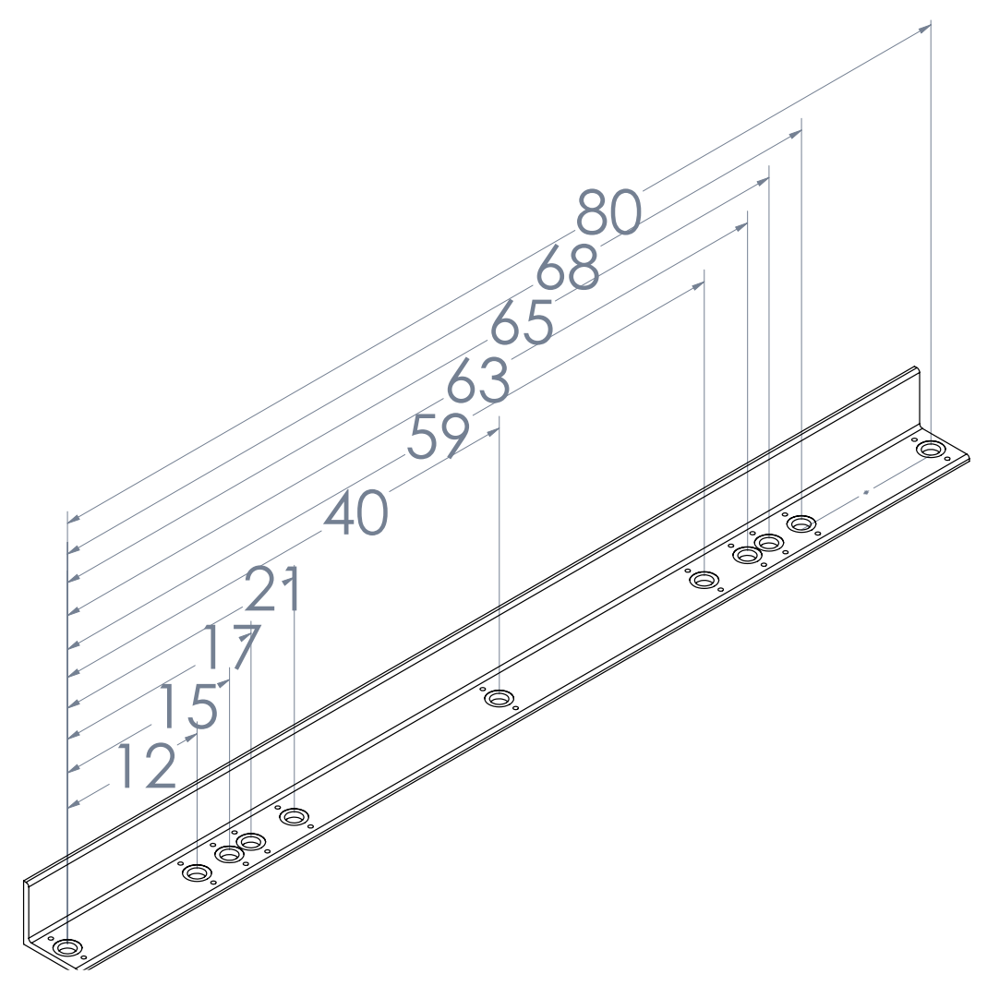
where $C_I(r)$ is the measured covariance, C_n^2 is a measure of the turbulence strength based on Kolmogorov turbulence theory, and the weighting function, $W(r,z)$, which accounts for many factors including wind speed, the shape of the Moon, the phase, and the apparent diameter.

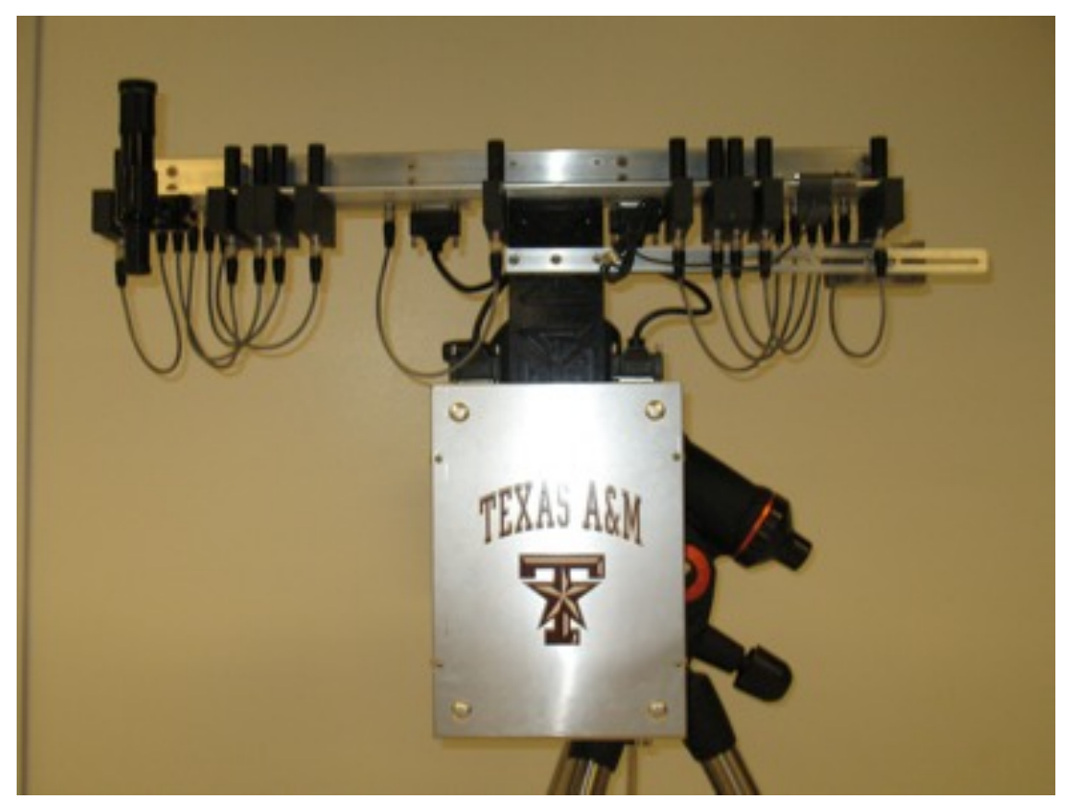


Example of the weighting function. The solid line is a single detector. Greater detector spacing probes higher peak atmospheric ranges.

Abstract

To develop next generation telescopes and adaptive optics (AO) systems, it is crucial to understand the characteristics of an astronomical site. Lunar scintillometers are an important tool to aid in this understanding. These instruments are able to measure atmospheric turbulence and its effect on astronomical seeing at the ground layer where telescope and observatory design play a role. Here we describe a new lunar scintillometer, MooSci, to aid in the site characterization campaign for the Giant Magellan Telescope (GMT). MooSci has been tested and confirmed to provide reliable data for the reconstruction of turbulence profiles.





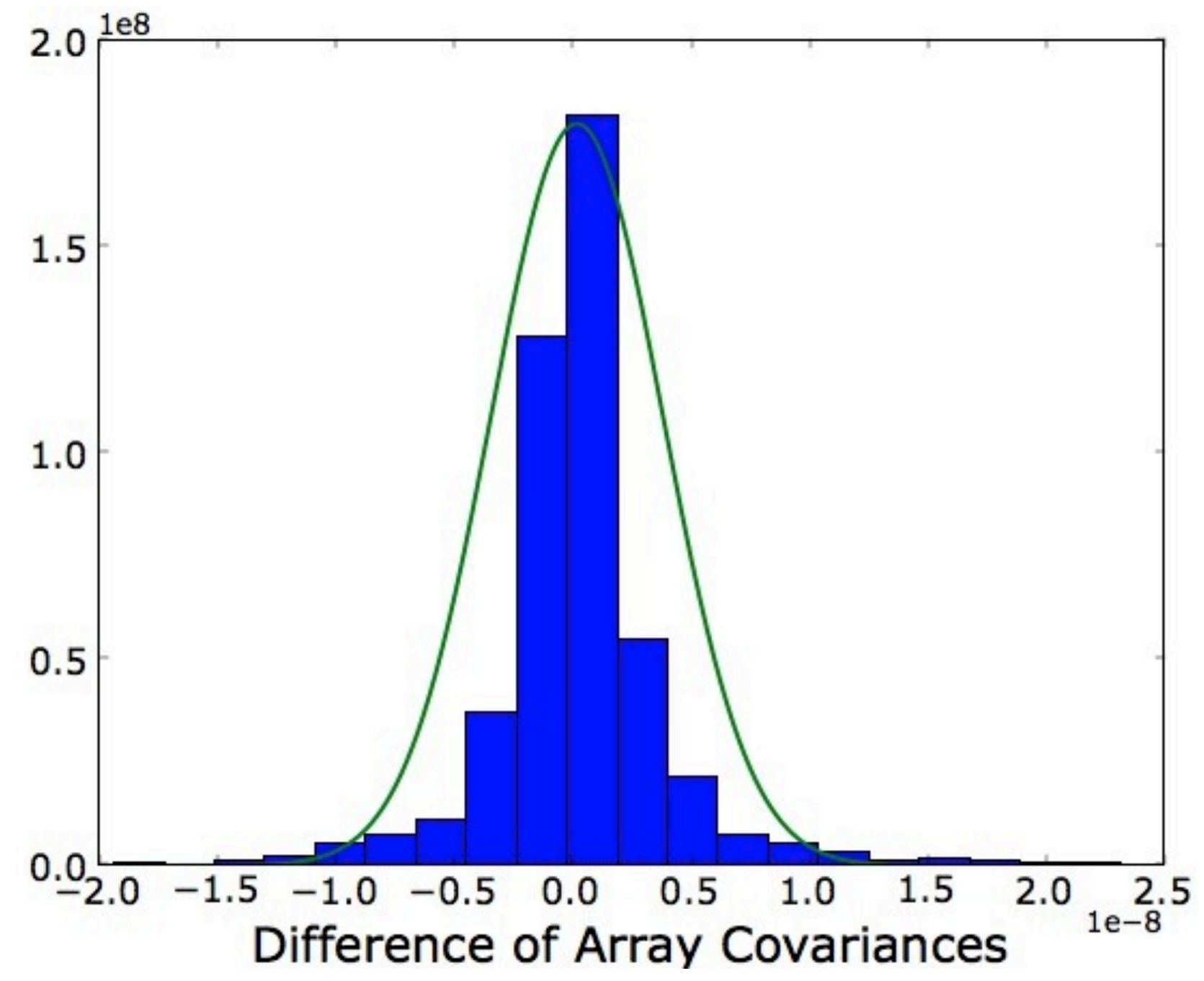
MooSci Design

MooSci is a 80 cm long linear array of 11 photodiode detectors. It has detectors placed at 0, 12, 15, 17, 21, 40, 59, 63, 65, 68, and 80 cm along the main beam. This gives the instrument a total length twice that of the LuSci design that it was based on, and allows it to probe higher into the atmosphere with a full range of 10 to 500m. MooSci can be used as a single array to probe the highest layers possible or as two co-located arrays. In the second of the two configurations MooSci provides a check on its own capabilities. Two units were built and deployed in the site characterization campaign for the Giant Magellan Telescope (Thomas-Osip et al. 2011).

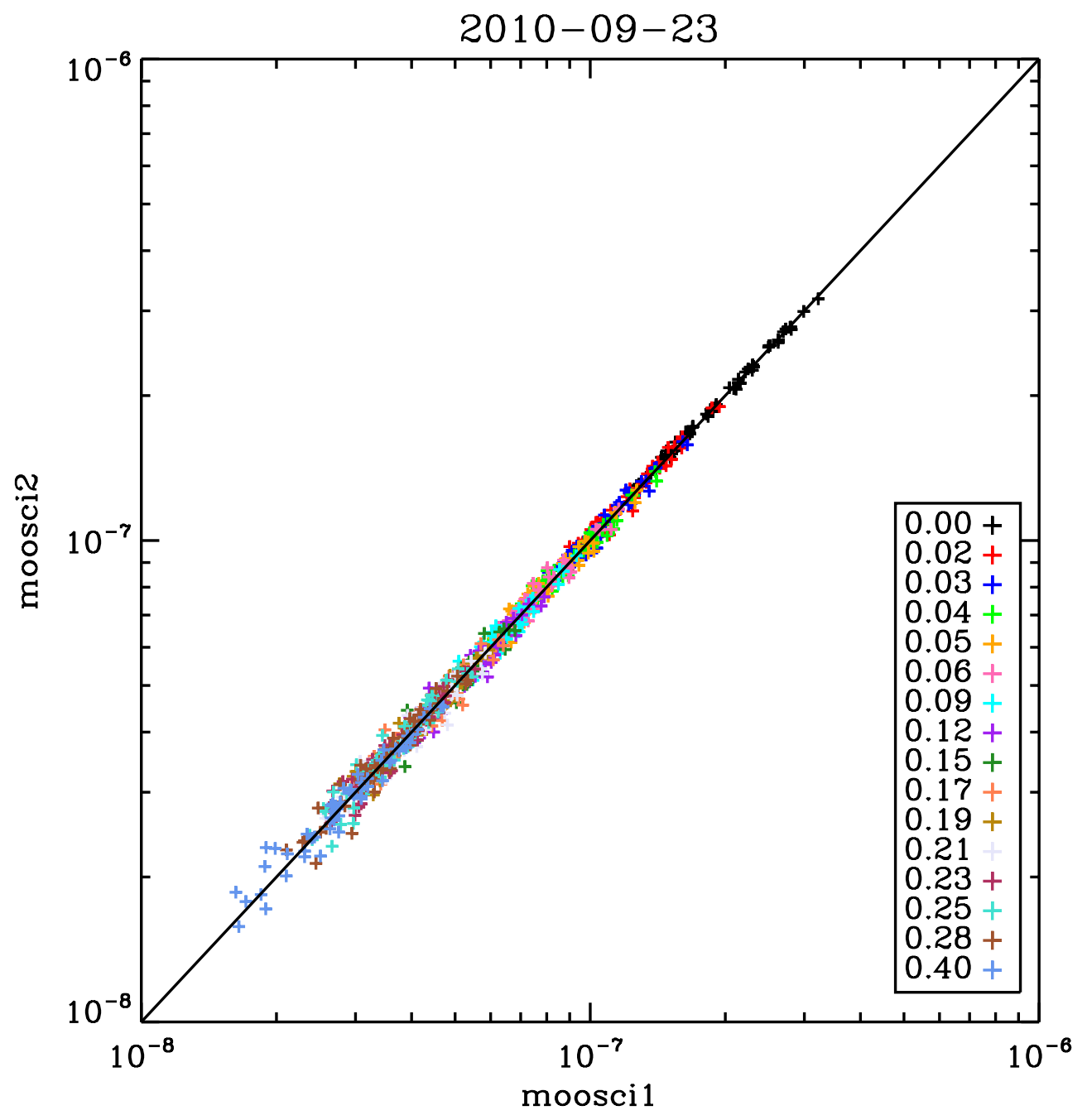
Testing

MooSci must achieve a Signal-to-Noise (S/N) of 10^4 in order to detect lunar scintillation. Simple tests comparing the voltage signal of the photodiodes to the standard deviation over a 5 second interval shows that MooSci achieves a S/N of 2.8×10^4 when the Moon is low in the sky and out of phase and 10^5 when it is full and transiting.

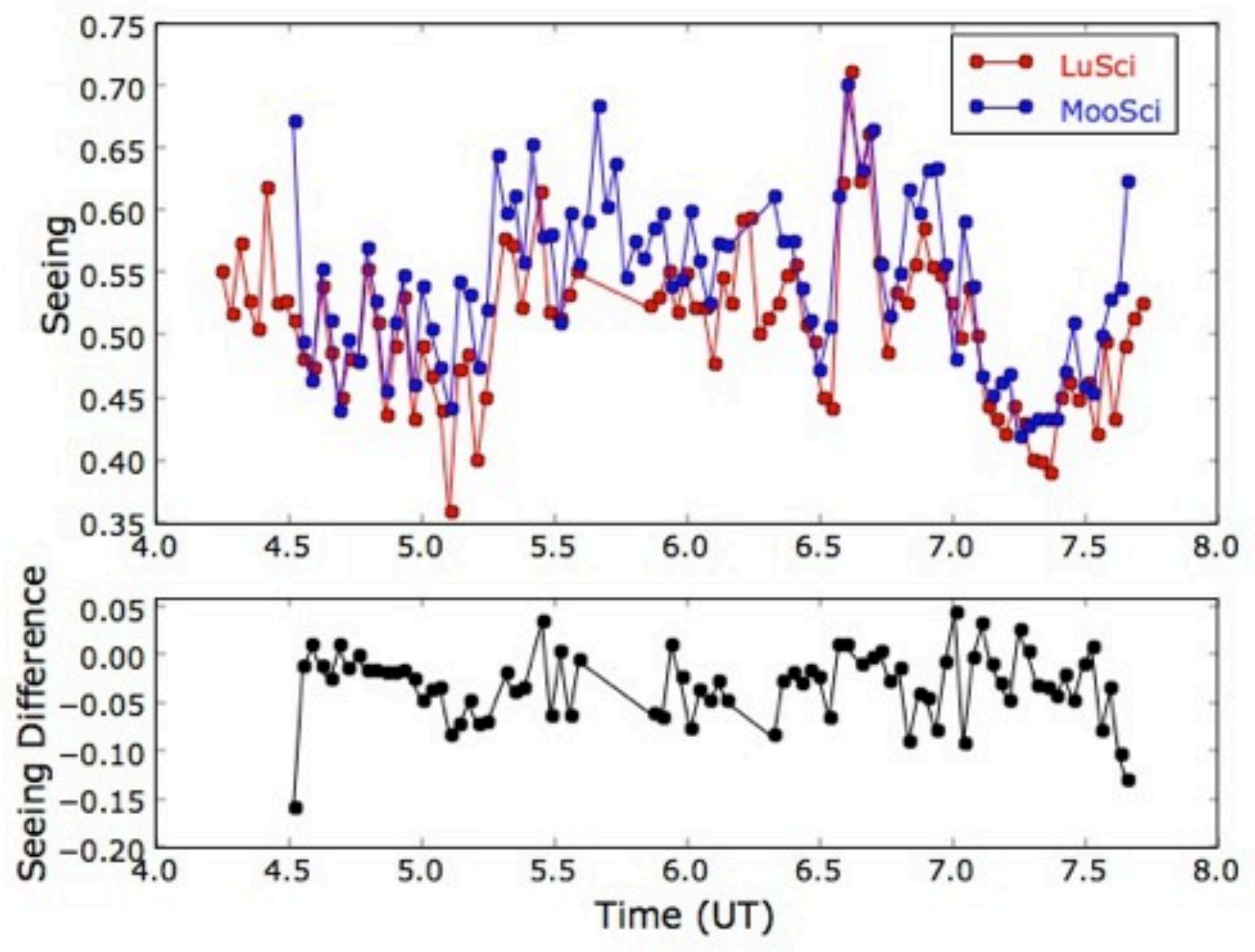
MooSci was also used as two 6 channel arrays. The difference in the covariance between each identical spacing on each array was found. A histogram of these differences was made. The variance and mean of the full data set was found and a Gaussian was plotted over the histogram.



The Gaussian has a mean of 2.6095×10^{-10} and a standard deviation of 3.6319×10^{-9}. The same covariances used for the differences are shown below as array 1 vs array 2. The symbols are the different detector spacings as shown in the key.



As a further test, MooSci was compared to LuSci which was operated in previous site characterization campaigns successfully. The seeing calculated from the measurements of both instruments agree well with a general offset. MooSci tends to measure a higher seeing as compared to LuSci.



MooSci has been shown to meet it's design goals while reliably measuring the seeing at a site as compared to itself and to existing scintillometers.

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GMT

HETDEX Illuminating the Darkness
Hobby-Eberly Telescope Dark Energy Experiment

LSST Large Synoptic Survey Telescope

DARK ENERGY SURVEY

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