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Generation of atmosphere-like optical turbulence

Stefan Hippler, Thomas Henning, Felix Hormuth, David Butler and Wolfgang Brandner

Using standard semiconductor processing equipment, phase screens etched on glass-plate surfaces can simulate scaled-down 3D atmospheric optical turbulence.

With the advent of second generation astronomical adaptive optics (AO) systems like multi-conjugate AO, ground layer AO, extreme AO, multiple field of view AO, and multiple object AO, it is becoming more and more important to have a realistic 3D turbulence simulation tool available in the laboratory. Such a tool provides repeatable optical turbulence and therefore well-defined atmospheric conditions. It can support the assembly, integration, and verification phases of novel AO instrumentation so that AO performance can be verified before the instrument is attached to the telescope.

An important parameter for the design of astronomical AO systems is the ratio D/r_0, where D is the telescope diameter and r_0 is the Fried parameter, the optical coherence length of the atmosphere. In reality, this ratio varies between 10 and 30 for existing 8m telescopes and observing wavelengths between 1 and 2.5µm. For laboratory characterization of astronomical AO systems designed for telescopes with D in the range of 8-40m, D/r_0 values greater than 30 are required. As we can use only scaled-down telescope optics in the laboratory, with typical values of D_{lab}=10mm, we need r_0 values smaller than D_{lab}/30=1/3mm. In the past, glass phase screens with such small r_0 values were difficult to fabricate.[1] The only tool we have identified for this problem, and therefore the best solution so far, is the surface etching technique.[2]

Glass-plate phase screens from Silios Technologies, France, are manufactured with a wet etch process based on hydrochloric acid. The equipment is similar to standard semiconductor processing equipment used for 4in. wafers. The phase pattern (see Figure 1) is etched into the 100mm diameter, 1.5mm- thick glass substrate consisting of fused silica (Corning code 7980). This high-purity amorphous silicon dioxide has very good transmission[2] in the required spectral range from 0.5 to 2.5µm. The phase screens are realized through a multilevel profile created with either five or six masks, which eventually lead to 32 and 64 different levels of the phase map.

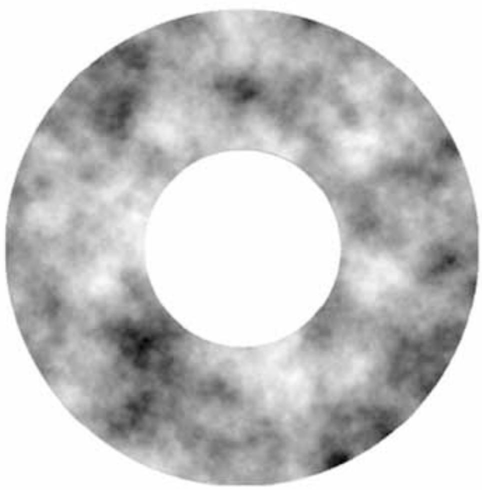

Figure 1. *Phase map of the 'high-layer' phase screen.*

MAPS (see Figure 2) is a laboratory tool we built to allow simulation of 3D atmospheric optical turbulence over a wide field of view up to 2arcmin.[3] It consists of three main components.

The first component, a reference plate for light sources, is composed of 34 fiber connectors to investigate wide-field wavefront reconstruction for various artificial-star configurations. The next element consists of two optical tubes containing identical groups of lenses fabricated by Janos Technology Inc., Keene, NH. The first tube collimates the point sources of the reference plate and creates the telescope pupil. The second tube refocuses the disturbed light beams into a 2arcmin-wide focal plane with the optical characteristics of the Very Large Telescope (VLT) f/15 Nasmyth focus.

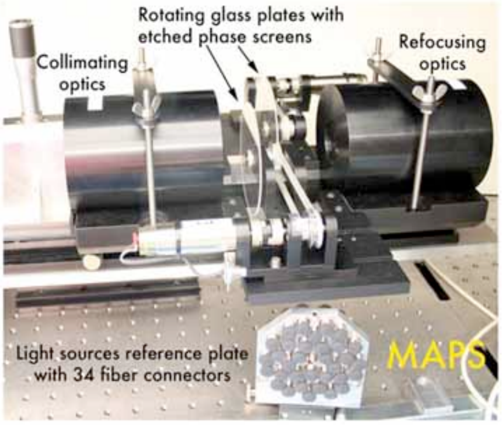

Figure 2. *The turbulence generator MAPS mounted on an optical bench. Two motorized glass-plate phase screens are located between the collimating and refocusing optics (black tubes). The light source reference plate can be seen in the foreground.*

The final component is a set of phase screens obtained from Silios Technologies, France. Up to three glass phase screens can be mounted in between the two optical tubes. When rotating, those screens simulate a turbulent atmosphere consisting of a ground or boundary layer, a mid-altitude layer, and a high-altitude layer. Each glass plate can rotate with an adjustable and reproducible speed to simulate different atmospheric wind speeds per layer. Additionally, we can adjust the position of each glass plate along the optical axis of the system to simulate atmospheric layers at different altitudes.

Point spread functions (PSFs) for a single phase screen measured with MAPS are shown in Figure 3. To measure these PSFs, we put a single phase screen at the ground layer position in the MAPS assembly, using a 13mm pinhole as the telescope aperture, equivalent to a real-world aperture of 8m. A single-mode fiber at the center of the field of view on the input side of MAPS was used as a light source. Measurements were made at two wavelengths, using a HeNe laser with λ=632.8nm and a diode laser with λ=831.5nm. A standard CCD with a pixel size of $6.9 \times 6.9\mu m^2$ was placed in the focal plane of the image side to record short-exposure PSFs. During measurement the phase screen typically was rotated at a speed of 0.5rpm, while the CCD acquired large sets of exposures (on the order of several thousand) with integration times of a few milliseconds. Afterwards, all short exposure images were stacked to generate the long-exposure PSF image. A speckle movie recorded with MAPS is available at http://www.mpia.de/homes/hippler/SpeckleMovie1.mpg.

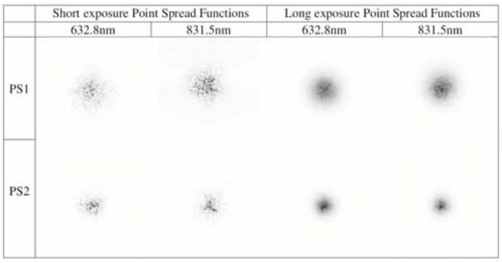

Figure 3. *These representative images illustrate both short- and long-exposure point spread functions for two different phase screens, PS1 and PS2, at 632.8 and 831.5nm. The data was taken with an aperture size of 13mm, equivalent to a real-world telescope size of 8m. The size of each image is 200 × 200 CCD pixels.*

Authors

Stefan Hippler, Thomas Henning, Felix Hormuth, David Butler, Wolfgang Brandner
Max Planck Institute for Astronomy
Heidelberg, Germany

www.mpia.de/homes/hippler

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