

MOAO test bench in Tohoku University

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We started AO development activities in Tohoku university targeting Multi-Object Adaptive Optics system for the next generation ground-based large telescopes. In an MOAO system, 3D structure of the atmospheric turbulence will be evaluated with wavefront measurements in multiple directions and tomographic reconstruction. The estimated 3D structure is integrated in the directions of targets and the optimized correction for each target will be applied as an open-loop correction. Applying the wavefront correction independently to each direction, each object is expected to be observed in a condition close to the diffraction limit. In order to evaluate the tomographic estimation method, we are assembling a test optical bench to simulate an MOAO system in our optical lab. The system consists with 1) four light sources with single-mode fibers simulating three natural guide stars and one target object, 2) multiple phase plates simulating atmospheric turbulence structure, and 3) 4 Shack-Hartmann wavefront sensors. Imaging data from the sensors will be reduced with tomographic algorithm using GPU-based PC. The accuracy of the tomographic wavefront estimation and the usage of the GPU-based PCs will be examined. Additionally, open-loop control of an AO system will be tested with an independent module. Once the method of open-loop control is established, the module will be installed in the tomography test bench and entire system will be evaluated as an MOAO system. Related activities, a development of a large stroke (20 micron) MEMS deformable mirror with large number of elements (>3000) is introduced.

Tomography test bench overview

The optical layout and entire view of the tomography test bench is shown in Figure 1. The bench has 4 light sources with single-mode fibers simulating three natural guide stars and one target object. The light from the sources are collimated with a lens and goes through a path simulating the atmosphere. In the path, multiple phase plates will be installed. In the initial evaluation shown below we installed one clear plastic plate at three positions representing turbulence at different height. In the next step, we will install a glass phase plate (d=100mm) from Lexitek with appropriate power spectrum and a spatial light modulator LC2002 from HOLOEYE to simulate multiple turbulence layers. A lens is used to simulate the primary of a telescope and the converging light are fed to four Shack-Hartmann wavefront sensors with collimation lens. In the wavefront sensors, 110um pitch micro-lens arrays with focal length of 22mm from SUSS MicroTec are attached in front of video-rate CCD camera.

At first, we evaluated the relative positions and directions of the wavefront sensors by putting a bar in the collimated light path corresponds to the atmosphere. Afterward, we put a plastic plate changing the distance from the "telescope primary" and measured the wavefronts from the light sources. The wavefront is reconstructed for each Shack-Hartmann WFS data with Fried geometry and Cholesky decomposition. The reconstructed wavefronts from three WFSs are tiled to compare with the wavefront of the central light path. The results are summarized in Figure 2. The wavefront for the central light path is reproduced from the data of the three WFSs. The difference is still relatively large for the bottom two configurations, and further investigations are necessary.

In parallel, we are developing a Shack-Hartmann wavefront sensors with E2V EM-CCD CCD060 with fast read-out of ~1,000 fps. Read-out electronics are purchased from Nuvu Cameras and currently evaluation setup is under preparation. Once the wavefront sensor is ready, we will replace the video-rate CCD cameras in the tomography test bench with the EM-CCD cameras.

Additionally, we started reducing WFS data with parall calculations with Graphics Processing Unit (GPU). Initial evaluation indicates 1500 spots on 648x494 images can be measured within less than 1msec with NVIDIA Tesla C2070. As a next step, we will feed the EM-CCD wavefront sensor data to the GPU and evaluate the possibility of using GPU in the wavefront reconstruction.

Open-loop AO test module overview

In order to evaluate the accuracy of the open-loop AO correction, we are constructing open-loop AO test module as shown in Figure 3. The module has two Shack-Hartmann WFSs, one for open-loop wavefront measurement (WFS1), and the other one for evaluation of the open-loop correction (or closed-loop operation, WFS2). The module has one 32ch membrane DM from ADAPTICA in the closed-loop path. The module is under calibration process with a lab light source on a optical bench as shown in the right panel of Figure 3. Currently measured wavefront on WFS1 and WFS2 are compared and cross-calibrated. In the bottom panel of Figure 3, WFS1 and WFS2 measurements of the wavefront through the Lexitek phase plate are shown. Overall wavefront structure measured with WFS1 and WFS2 are consistent, but still there are non-negligible difference exists and further cross-calibration is necessary. Once the cross-calibration is established we will calibrate the movement of the deformable mirror with WFS2 and test the open-loop AO correction on the optical bench. After the testing on the optical bench, we will attach the module to a small telescope and evaluate the on-sky performance of open-loop AO correction.

MEMS deformable mirror development

In order to achieve sufficient wavefront correction on the >30m class telescope, we require deformable mirror (DM) with elements more than ~3000. Furthermore, actuator stroke of 20um is required to correct turbulence in low-order modes within the >30m aperture and a few um for the highest spatial frequency mode. Additionally, the size of the DM needs to be sufficiently small for the necessity of multiple modelus in an MOAO system. In order to realize a DM with large stroke, we started development of DM with Micro Electro Mechanical Systems (MEMS) technology based on a new design.

The schematic structure of the prototype MEMS-DM is shown in the left panel of Figure 4. In order to realize the 20um stroke in the low-spatial frequency mode, a gap as large as 80um between the surface mirror and the supporting base electrode is necessary. We use a bimorph-spring structure made by a crystallization process to realize the large gap. The amount of compressive stress due to the crystallization process implies that 150um spring length is necessary to make 80um gap. Such bimorph spring is connected to the membrane mirror with Au-Si bonding. Currently we are constructing various prototypes by chaging spring structure. Examples of the structures observed with IR transparent microscopic view are shown in Figure 4. Once the expected gap is achieved, we will examine the properties of the structure.

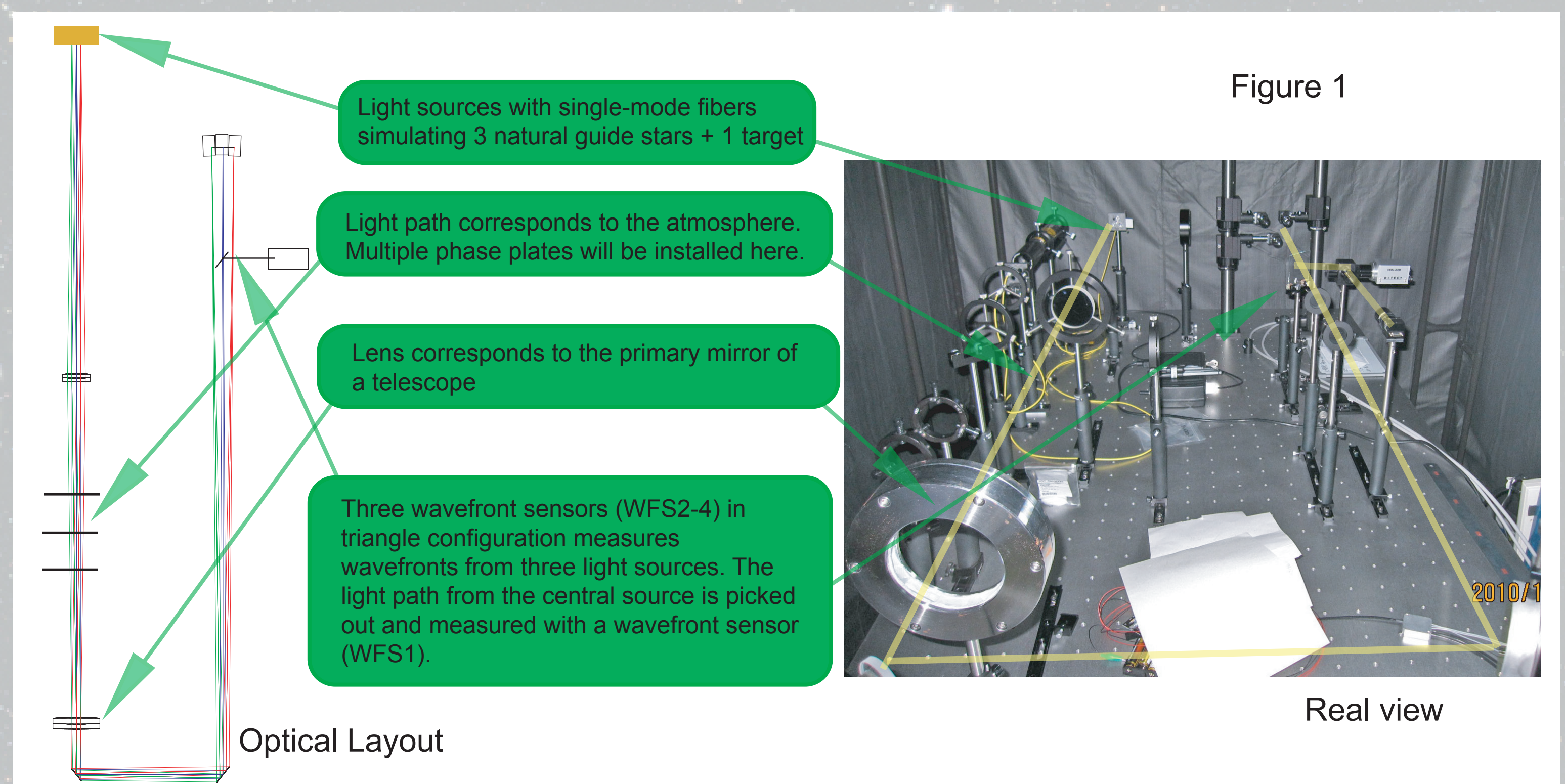


Figure 2

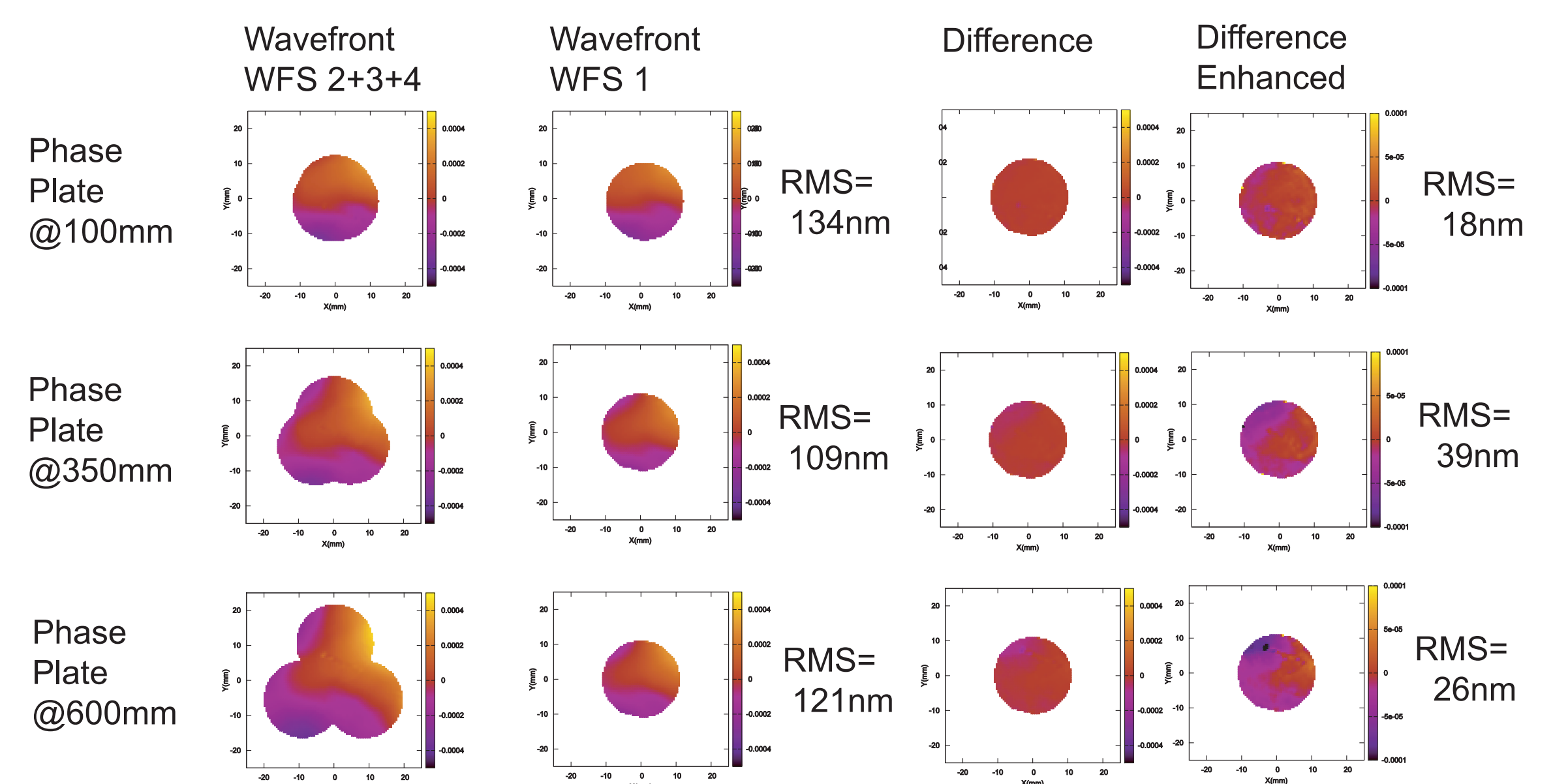


Figure 3

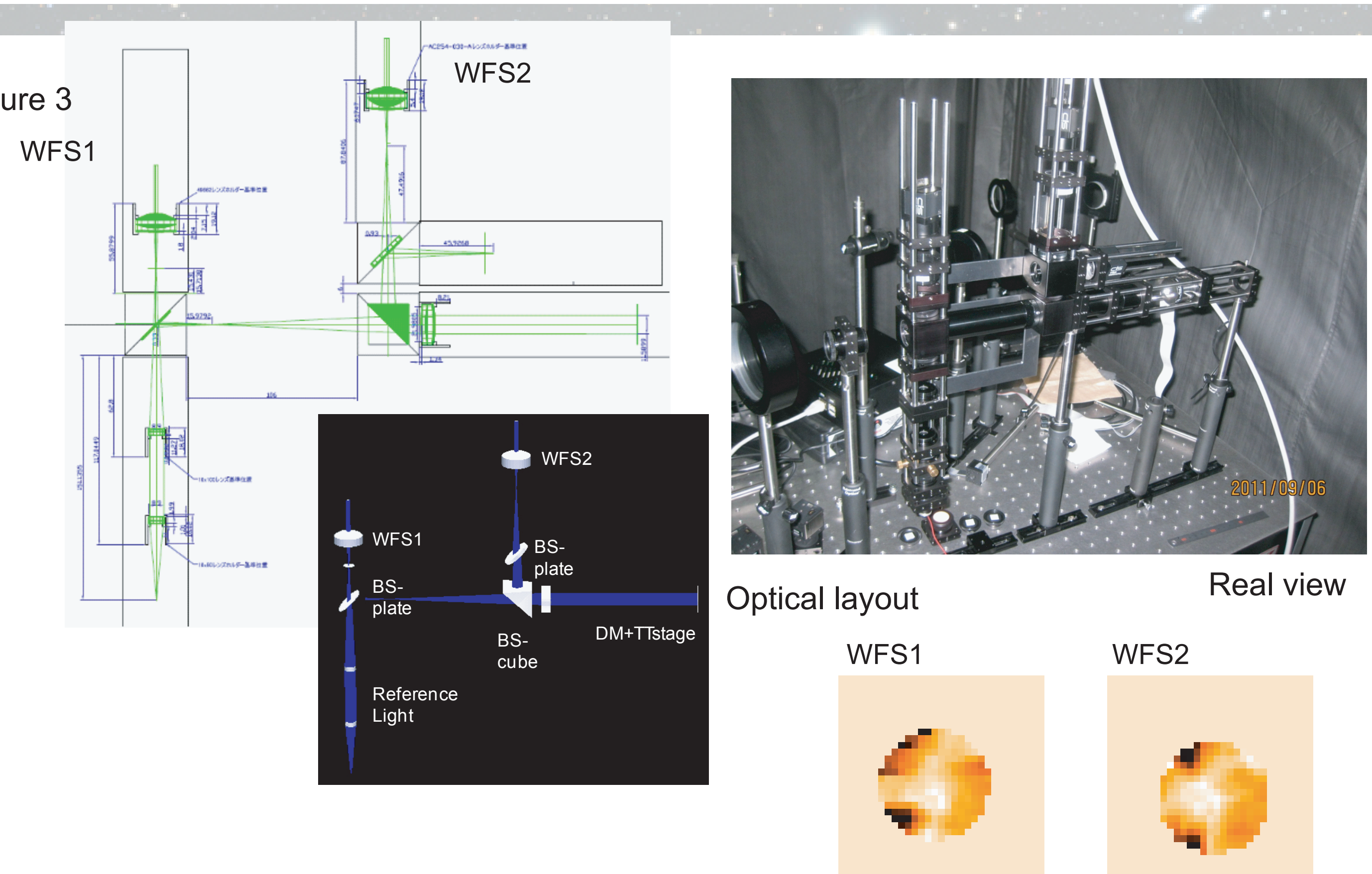


Figure 4

