Low speckle noise coronagraph with UNI+PAC

T. Kotani[1], J. Nishikawa[2], K. Yokochi[3], N. Murakami[2], L. Abe[2], M. Tamura[2], T. Kurokawa[3], A. Tavrov[2], M. Takeda[4]

[1] LESIA, Paris observatory, [2] National Astronomical Observatory of Japan, [3] Tokyo University of Agriculture and Technology, [4] The University of Electro-Communications

Abstract

Unbalanced nulling interferometer (UNI) and phase and amplitude correction (PAC) by an adaptive optics system with two deformable mirrors is a novel pre-optics of a coronagraph which can absorb the dynamic range (the central star intensity and the speckle intensity) of about 10^{-2}. UNI makes a wavefront error magnification and after that the error can be virtually compensated beyond the AO limit, e.g., getting λ/10000 quality wavefront by λ/1000 optics. A space coronagraph which has a dynamic range of 10^{-8} with λ/1000 quality combined with the UNI-PAC can achieve total dynamic range of 10^{-10} with λ/1000 wavefront quality throughout the optics. In an experiment, we confirmed the error magnification by the UNI (λ/80 -> λ/20, under the central star reduction ratio is 5%) and we are now trying to compensate the magnified wavefront errors and observe the reduced speckle intensity with a common-path AIC nulling coronagraph.

Concept

For the direct detection of Earth-like planets, reducing speckle intensity below the planet level is a key issue as well as the suppressing diffracted light from parent star using a coronagraph. We propose a novel technique based on a pre-optics setup that behaves partly as a moderate efficiency coronagraph, and partly as a high-sensitivity wavefront error compensator (Nishikawa et al. 2006). First, the wavefront electric field of a star is partly cancelled by an intensity-**Unbalanced Nulling Interferometer (UNI)** . Then the recombined output wavefront has its input errors magnified. Thanks to the unbalanced recombination scheme, the wavefront has not phase singular points (zeros) and therefore the wavefront errors can be corrected by a downstream **Phase and Amplitude Correction (PAC)** adaptive optics system, using two deformable mirrors (DMs). The magnification of error wave followed by two DMs will dramatically increase a sensitivity to detect and correct very small wavefront errors. With this pre-optics, the wavefront quality and the star intensity suppression level for a downstream coronagraph are largely relaxed.

Fig. 1 shows the proposed layout of the UNI-PAC. The light from a single telescope is collimated and spatially divided into two beams. The amplitude of one beam is reduced by a factor of g and π phase shifted relative to the other beam. Then two wavefronts are combined by a beamsplitter. The error-free wavefront is reduced by a destructive interference, however the error components remain at almost same levels as initial wavefronts. The intensity reducing of one beam is needed to avoid phase singularity in the pupil plane. The final error amplitude normalized by error-free wavefront is about 5 times magnified relative to the initial wavefront error, if g = 0.2 is adopted. Fig. 2 illustrates these processes.

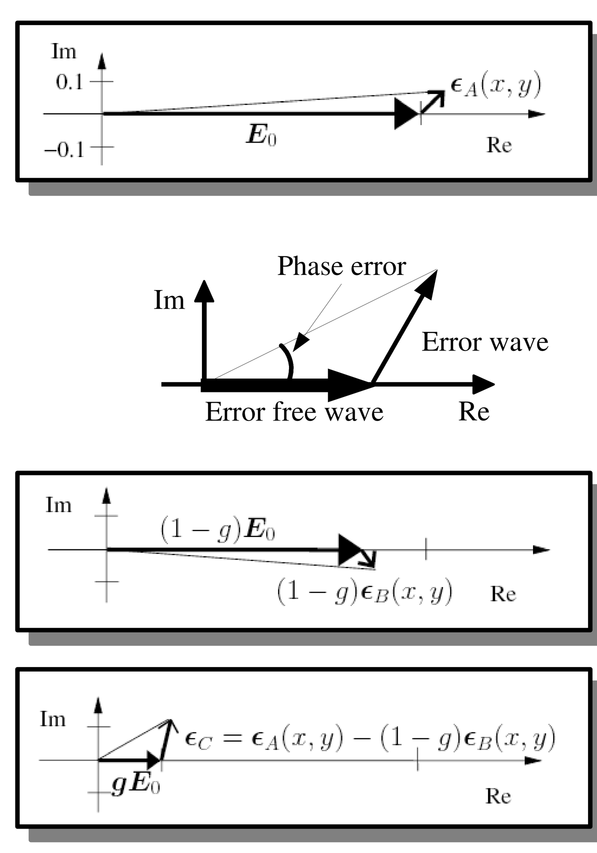

Fig. 2. Complex amplitude of an (x, y) point in the pupil plane. In each panel, an arrow from the origin indicates the error-free amplitude, and the complex error component, is shown by other small arrow.

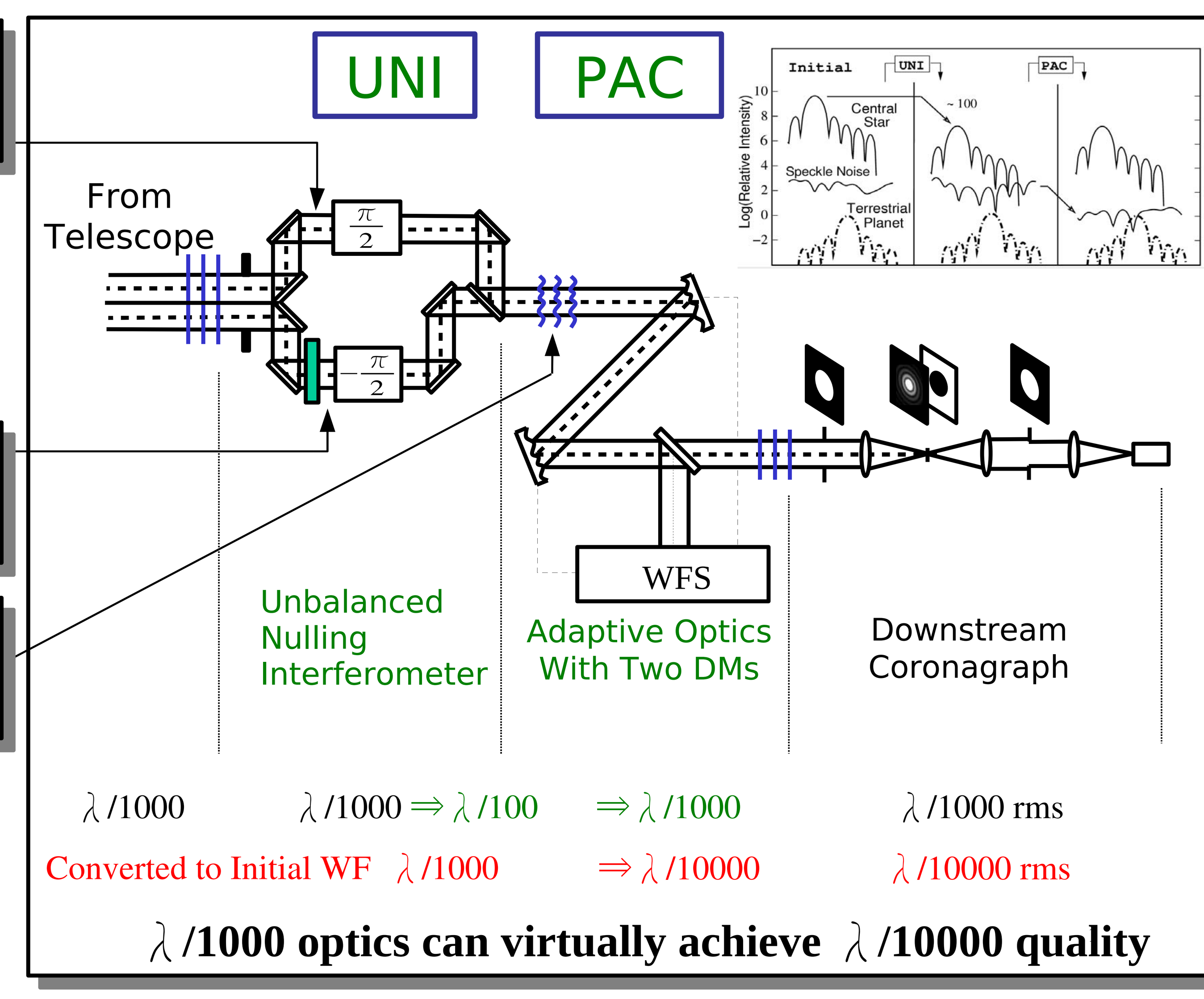

Fig. 1. Schematic layout of UNI-PAC

Error Magnification Experiment

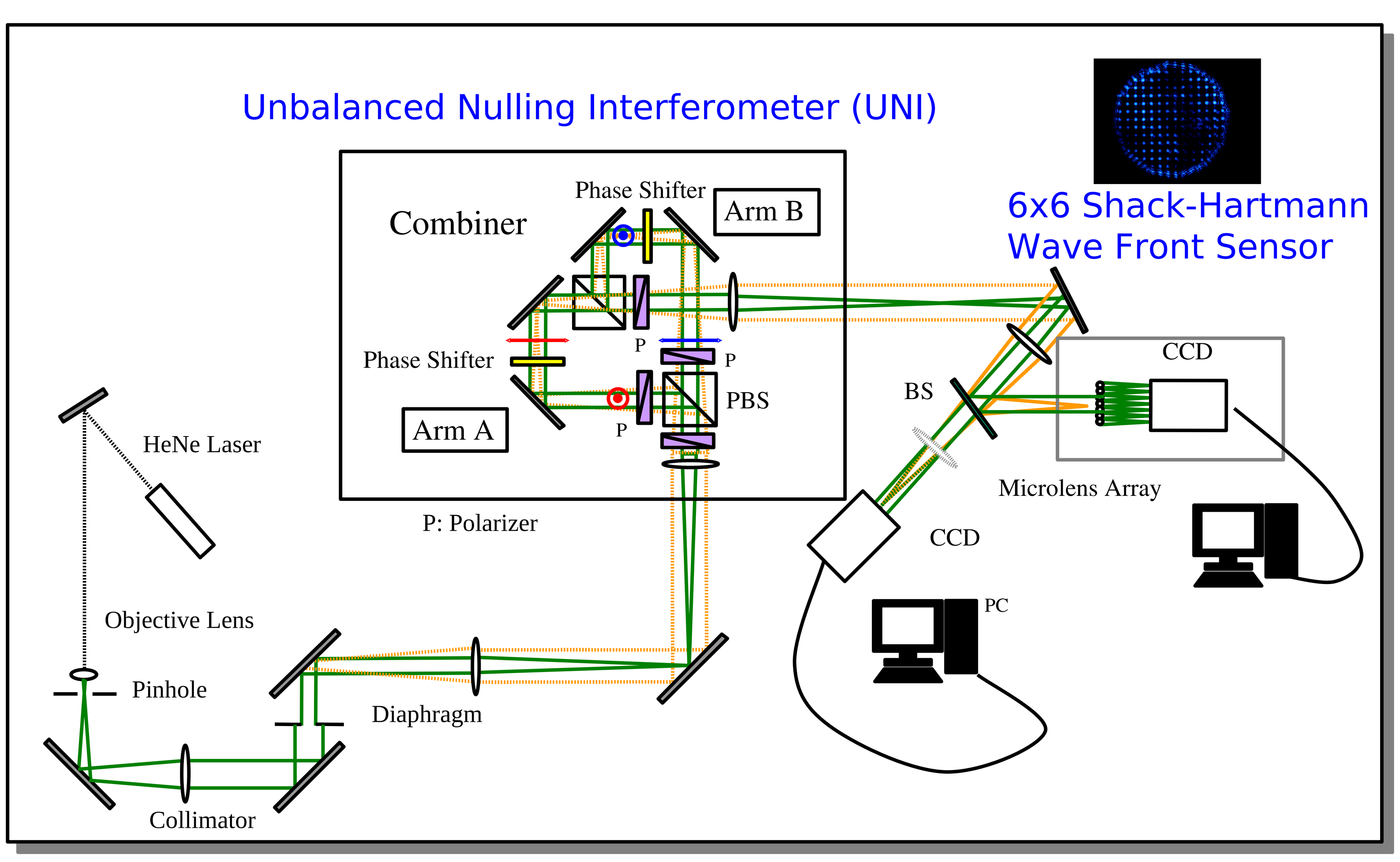

Fig. 3. Experimental setup of the UNI.

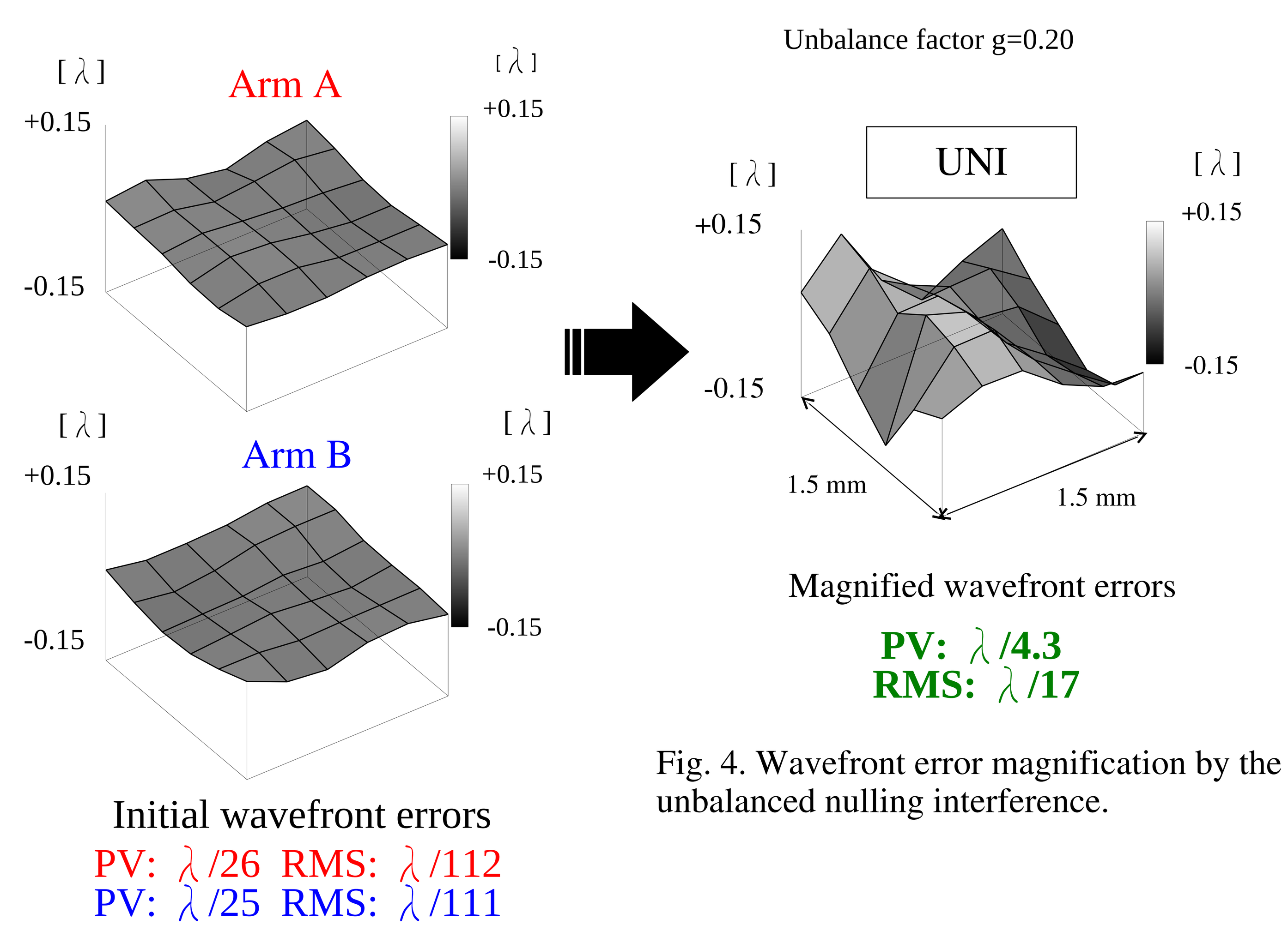

Fig. 4. Wavefront error magnification by the unbalanced nulling interference.

We have constructed the laboratory testbed to demonstrate a capability of the UNI-PAC for very precise wavefront correction (Fig. 3). In the experiments, two beams are generated by a beam splitter and they are combined by another beam splitter under an intensity-unbalanced nulling condition. The phase shifter introduce π phase shift between two beams. After the UNI, the Shack-Hartmann wavefront sensor is used to measure the wavefront errors. Fig. 4 shows the measurements of the initial and magnified wavefront errors after the UNI. The errors are magnified by a factor of 6.6, as predicted by our theory (Fig. 5).

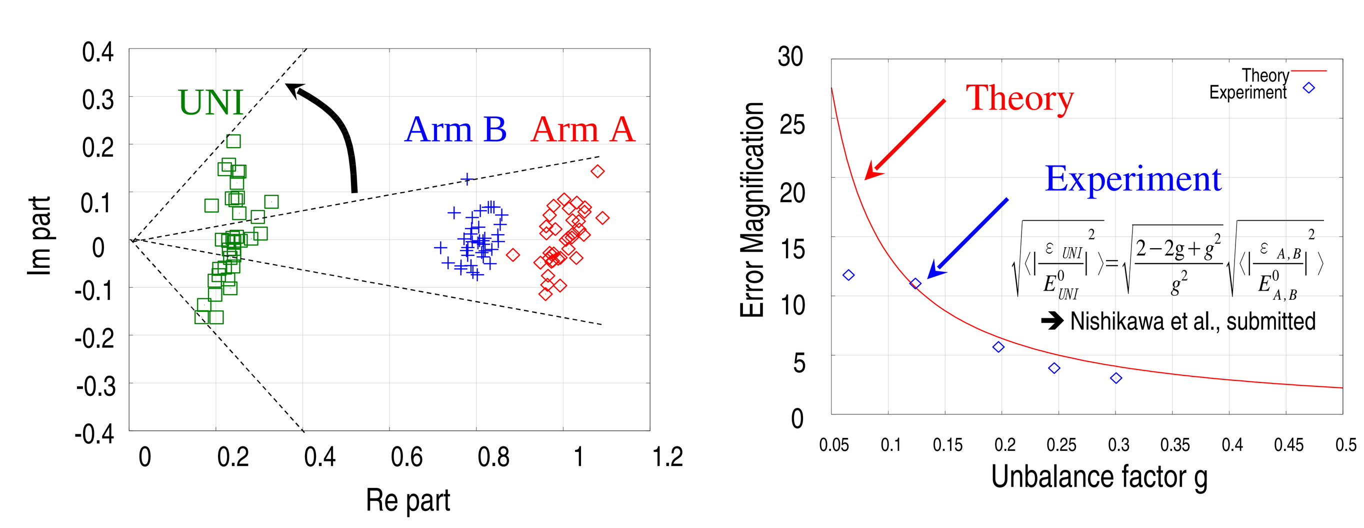

Fig. 5. Left: Measured complex amplitudes in the wavefronts. Right: Measured error magnification factors against the unbalaced factors.

Perspective

The UNI-PAC method will dramatically enhance a capability of a wavefront sensing and correction with a standard AO system. Our laboratory experiments have demonstrated that the wavefront errors are successfully magnified by the UNI, which is an important step towards very precise wavefront correction. We are now trying to compensate the magnified wavefront errors by two deformable mirrors and observe the reduced speckle intensity with a common-path nulling coronagraph (Tavrov et al. 2005) as a downstream coronagraph. Some other problems, such as an achromatism, resolved star diameter, and AO performance limitations are being investigated.

References

1. J. Nishikawa et al. 2006, A&A submitted
2. J. Nishikawa et al. 2006, Proc. SPIE, 6265, 3Q1-3Q5
3. A. V. Tavrov et al. 2005, Opt. Lett. 30, 2224-2225