Low speckle noise coronagraph with UNI+PAC

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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 10⁵. 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 10⁵ with λ/1000 quality combined with the UNI-PAC can achieve total dynamic range of 10⁷ with λ/10000 wavefront quality throughout the optics. In an experiment, we confirmed the error magnification by the UNI (λ/80 → λ/20, 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 reconstructed output wavefront has its input errors magnified. Thanks to the unbalanced recombination scheme, the wavefront has not phase singular point (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 wavefront 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.

Unbalanced Nulling Interferometer (UNI)

Unbalanced nulling interferometer magnifies wavefront errors and allows for the virtual compensation beyond the AO limit, e.g., getting λ/10000 quality wavefront by λ/1000 optics. The wavefront quality is reduced by a destructive interference, however the error components remain at almost the same levels as initial wavefronts. The intensity reducing factor of 10⁵ has not phase singular points (zeros) and therefore the wavefront errors can be corrected by an adaptive optics system with two deformable mirrors. The amplitude of one beam is reduced by a beamsplitter. The error-free wavefront is reduced by a destructive interference, however the error components remain at almost the same levels as initial wavefronts. The intensity reducing factor of 10⁵ has not phase singular points (zeros) and therefore the wavefront errors can be corrected by the PAC system.

Phase and Amplitude Correction (PAC)

The PAC system is used to virtually correct the magnified wavefront errors. The wavefront electric field of a star is partly cancelled by an adaptive optics system with two deformable mirrors (DMs). The magnification of error wavefront 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.

Error Magnification Experiment

We have constructed the laboratory testbed to demonstrate a capability of the UNI-PAC for very precise wavefront correction. In the experiments, two beams are generated by a beam splitter and they are combined by another beam splitter under an intensity-unbalanced nulling interference. The phase shifter introduces a 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).

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