Linear Wavefront Control for High Contrast Imaging

Olivier Guyon (University of Arizona), PI

Direct imaging and spectroscopic characterization of habitable exoplanets requires high contrast imaging capability, which is achieved by combining a coronagraph and a high performance wavefront control system. Wavefront stabilization is the most significant fundamental challenge to this endeavour. An Earth-like planet is approximately 1.5e-10 times as bright as the star it orbits, and at λ=500nm, a pupil plane sine wave aberration of 2 picometer amplitude is sufficient to create an equally bright speckle. The wavefront stabilization challenge is fundamentally a tradeoff between sensing sensitivity and optical stability.

Imaging systems operating at high contrast currently use focal-plane wavefront sensing and control: unwanted speckles in the focal plane are probed by a known set of deformable mirror (DM) actuations so that their amplitude and phase can be recovered and then canceled by introducing speckles of opposite complex amplitude. This process, referred to as Electric Field Conjugation (EFC), creates in the image a dark field (DF) suitable for high-contrast imaging. Measurement cycles must be repeated sufficiently frequently to track wavefront changes, and can be time-consuming due to the small amount of light available in the DF. The corresponding images may not be scientifically useful due to the added starlight component.

We propose an efficient alternative to this process, locking the DF using bright speckles located outside the dark field, in both spatial and spectral dimensions. Changes in these bright field (BF) regions are highly correlated to the same wavefront changes that spoil the deep halo suppression in the DF. Because the BF images are significantly brighter than the DF images, they can be acquired at higher cadence, and no starlight needs to be directed to the DF during science exposures. By calibrating or computing the linear changes in the BF against wavefront changes, a linear dark field control (LDFC) servo can maintain high-contrast in the DF during science exposures.

Recent LDFC laboratory results, together with numerical closed-loop simulations, have demonstrated LDFC#s concept and critical functions (TRL3) but not validated LDFC in a relevant dynamical environment. We will further mature the approach through (1) advanced numerical simulations, (2) operation in a relevant high contrast imaging instrument system environment and (3) performance demonstration for dark field stabilization at high contrast. LDFC will be operated in spatial (using a bright light outside the dark hole), spectral (using out-of band light in the dark hole) and spatial+spectral modes. System-level dynamical validations will be conducted off- and on-sky at the Subaru Coronagraphic Extreme-AO Instrument (SCExAO) with an integral field spectrograph and multi-band imaging cameras. High performance will be validated at University of Arizona, NASA Ames and JPL's High Contrast Imaging Testbed (HCIT) to demonstrate, without DM probing, speckle stabilization at the 1e-9 contrast level in a 1e-8 stability test environment.

LDFC directly addresses the wavefront stability challenge in high contrast imaging by enabling much-needed continuous wavefront updates that would otherwise only be possible on the brightest targets. The bright speckles signal also provide a sensitive measurement of residual variations of the electric field in the dark field during observations, allowing accurate calibration of contrast residuals. The wavefront control approaches we will develop will considerably relax stability requirements for future space telescopes and high contrast imaging hardware (such as DMs). On segmented apertures, LDFC will efficiently track and correct segment cophasing errors, enabling coronagraphic imaging with the large aperture(s) required for spectral characterization of habitable worlds.