Introduction

The success of ground-based, high contrast imaging for the detection of exoplanets in part depends on the ability to differentiate between quasi-static speckles caused by aberrations not corrected by adaptive optics (AO) systems, known as “non-common path aberrations” (NCPAs), and the planet intensity signal. Frazin (2013, ApJ) introduced a post-processing algorithm demonstrating that simultaneous millisecond exposures in the science camera and wavefront sensor (WFS) can be used with a statistical inference procedure to determine both the series expanded NCPA coefficients and the planetary signal. The algorithm can be summarized as follows:

Focal plane intensity can be written as:

\[ I(p,t) = u_y^2 \cdot i_y(p,t) + A(p,t) + a' b(p,t) + b'(p,t) a + a' C(p,t) a \]

\( u_y \) is the field amplitude of the planetary signal, \( i_y \) is related to the planetary intensity, \( A \) is a vector of static aberration coefficients, \( a' \) is intensity only depending on AO residual (\( \phi_r \)) speckles, \( C \) depends on the static aberration (\( \theta_r \)) modulated by the AO residual, and \( b \) depends on the mixing of both effects.

Decompose Quasi-static NCPA: \( \psi_y(r) = \sum_{k=1}^{K} \psi_k(r) \) from \( k = 1 \) to \( K \), with \( \psi_k(r) \) being the functions in the search basis

Consider N locations \( \{p_1, \ldots, p_n\} \) one desires to know if there is a planet and how bright it is, and \( T \) exposures synced with AO system WFS measurements:

\[ y = H x \]

\[ y = [y_1, \ldots, y_T] \] where each \( y_i \) is \( I(p_i,t) - A(p_i,t) \)

\[ H = [H_1, \ldots, H_T] \] where \( H_i = [i_y(p_i,t), b_y(p_i,t), b'_y(p_i,t), c(p_i,t)] \)

Solve for \( x = [u_y; a; a' a] \) using a linear solver

Verifying and Exploring the Algorithm

The first steps were to recreate and verify the results of the Frazin Algorithm (FA). With this done, several simulated experiments were run to probe the accuracy of the resulting estimation of the NCPA after a given number of measured exposures versus factors such as strehl ratio, overall strength of the NCPA, and the number of functions (\( \psi_k(r) \)) included in the search basis set.

Simulating the FA in Real Time with Ideal Conditions

Simulations using the ideal coronagraph, ideal wavefront sensor, no noise in measurements, place only aberrations for the atmospheric effects and the NCPA, and an injected planet PSF are run to feed focal plane intensity frames into the FA. Every 150 exposures, the FA generates an estimate of the NCPA and applies a correction.

Adapting the Algorithm for Real-Time Use

In order to use this algorithm in real-time, it must be made more computationally efficient. To accomplish this, Eq. 1) is remapped so that \( y = H x \) no longer produces estimates of the planetary signal, seen in Eq. 2.

\[ I(p,t) - A(p,t) - u_y^2 i_y(p,t) = a' b(p,t) + b'(p,t) a + a' C(p,t) a \]

We have named this the Real-Time Frazin Algorithm (RTFA), and assume that \( i_y \) is zero in order to remove estimating any planetary signal from the algorithm (See Figure 3 for analysis).

Simulating the RTFA with Imperfect Knowledge of the AO Residual

In order to determine the effects of a real world AO system, the simulations are re-evaluated using low-order estimations of the AO residual in place of ideal WFS measurements.

References