National Aeronautics and Space Administration

Optimizing detection and characterization of exoplanets in high-contrast Imaging data

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Program: FY21 SURP **Strategic Focus Area: Extra-solar planets and star and planetary formation**

Objectives: To explore the limits of Aperture Masking Interferometry (AMI) with the NASA/ESA/CSA James Webb Space Telescope (JWST) and compare it with other techniques to find and characterize exoplanets and to help in finding protoplanets within circumstellar disks. Our goal here is to explore under which conditions of wavefront error, calibration, input scene, and brightness of the central host, AMI, KPI, or the techniques of direct imaging provide superior contrast.

Background: Direct detection of spatially resolved exoplanets as a function of wavelength provides estimates of temperature, luminosity (and thus radius), and composition which are complementary to dynamical masses provided by RV and astrometry, demographic constraints from microlensing, and radii from transits (and thus in conjunction with dynamical masses, information on bulk composition). Access to orbital radii 10-50 AU is crucial to study gas giant planets comparable to Jupiter and Saturn in formation around young stars **requires 0.1" spatial resolution at the distance of nearby star-forming regions (25-150 pc)**. The AMI mode on the NIRISS instrument was designed to provide spatial resolution as small as 0.5 λ/D with JWST a factor of 4-8x **improvement in Inner Working Angle (IWA) compared with JWST/NIRCam's Lyot coronagraphs with 4-6 λ/D**, resulting in an IWA of **~0.1" vs. 1"**. Our Bayesian data analysis framework developed in the FY20 R&TD_ESI is being applied to JWST data and tailored to specific types of data by the student, whose work is funded through this SURP proposal. We are demonstrating the benefits of our methodology to the community via the science enabled by our method; disseminating our methodology framework and its usage by the community; and enabling new scientific findings and potentially driving new approaches in the field. Finally, this collaborative SURP work strengthens the collaboration with our external partners.

Approach and Results: To achieve our goals we are **improving and adapting our Bayesian approach developed during a R&TD_ESI proposal to model AMI and NIRCam, taking advantage of information, such as wavefront sensing and control (WFSC) system data on JWST, to estimate simultaneously instrumental aberrations and the object scene** (*Ygouf et al. 2013, Ygouf, Rocha et al. 2020*). This approach provides a robust determination of faint astrophysical structures around a bright source. Current Improvements include significant speed ups of both the Least squares and the new MCMC implementations; performance validation (e.g maps are passed on the fly as variables; parallelized mode runs; iterative scheme to estimate the Zernike coefficients that describe the Wave Front Sensing Error (WFE); use the 10 first Zernike coefficients estimated with LS approach as priors in the estimation of the full 30 modes with the LS (and in implementation phase with MCMC sampling); corrected Noise model and WFE units). We achieve better results if we first fit for the lower order Zernike coefficients and use those as priors to constrain higher order coefficients. Results are shown below.

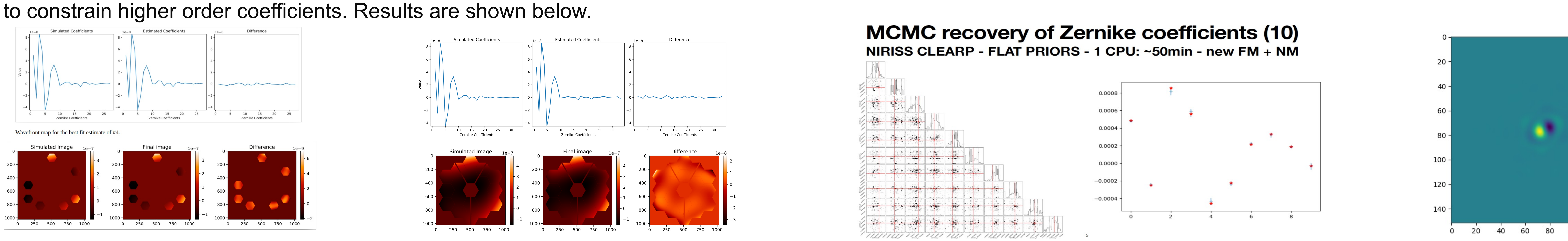

Figure 1. From left to right: Estimation of the Zernike Coefficients describing the Wave Front Errors using the LS approach: 1st panel - for AMI and 2nd panel - for Full Pupil Imaging. Estimation of the Zernike coefficients with MCMC for the new (correct) noise model used in the reconstruction algorithm: 3rd panel - 2-d contour plots and posterior distributions of the first 10 Zernike coefficients estimated for NIRISS Full Pupil Imaging; 4rd panel – maximum likelihood value of the (unbiased) estimated coefficients (blue) and the true values of the coefficients (red) used to generate the input simulations; 5th panel- residual image generated from the forward model and from the recovered parameters on the PSF, the residuals are mainly dominated by the uncertainty on the value of the first recovered Zernike coefficients.

Significance/Benefits to JPL and NASA: An unbiased estimator and optimized code for estimation of the WFE for both NIRCAM and AMI on NIRISS is a crucial step for the success of our project: we are now poised to pursue the science goals of our program This partnership supports JPL's strategic vision by giving the opportunity to further develop and apply our innovative method to analyze data from JWST. In the long-term, it will help in modeling the performance of WFIRST/CGI and future direct imaging flagships. Hence this work supports JPL's competitive position in proposing for new JWST programs and with new exoplanet missions. **Publication:** ***De Furio, M. et al., 'Optimizing detection and characterization of exoplanets with HCI', prep***