



### **On-Orbit Multi-Field Wavefront Control With a Kalman Filter**

A document describes a multi-field wavefront control (WFC) procedure for the James Webb Space Telescope (JWST) on-orbit optical telescope element (OTE) fine-phasing using wavefront measurements at the NIRCcam pupil. The control is applied to JWST primary mirror (PM) segments and secondary mirror (SM) simultaneously with a carefully selected ordering. Through computer simulations, the multi-field WFC procedure shows that it can reduce the initial system wavefront error (WFE), as caused by random initial system misalignments within the JWST fine-phasing error budget, from a few dozen  $\mu\text{m}$  to below 50 nm across the entire NIRCcam Field of View, and the WFC procedure is also computationally stable as the Monte-Carlo simulations indicate.

With the incorporation of a Kalman Filter (KF) as an optical state estimator into the WFC process, the robustness of the JWST OTE alignment process can be further improved. In the presence of some large optical misalignments, the Kalman state estimator can provide a reasonable estimate of the optical state, especially for those degrees of freedom that have a significant impact on the system WFE. The state estimate allows for a few corrections to the optical state to

push the system towards its nominal state, and the result is that a large part of the WFE can be eliminated in this step. When the multi-field WFC procedure is applied after Kalman state estimate and correction, the stability of fine-phasing control is much more certain.

Kalman Filter has been successfully applied to diverse applications as a robust and optimal state estimator. In the context of space-based optical system alignment based on wavefront measurements, a KF state estimator can combine all available wavefront measurements, past and present, as well as measurement and actuation error statistics to generate a Maximum-Likelihood optimal state estimator. The strength and flexibility of the KF algorithm make it attractive for use in real-time optical system alignment when WFC alone cannot effectively align the system.

*This work was done by John Lou, Norbert Sigrist, Scott Basinger, and David Redding of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45793*

### **The Interplanetary Overlay Networking Protocol Accelerator**

A document describes the Interplanetary Overlay Networking Protocol Accelerator (IONAC) — an electronic apparatus, now under development, for

relaying data at high rates in spacecraft and interplanetary radio-communication systems utilizing a delay-tolerant networking protocol. The protocol includes provisions for transmission and reception of data in bundles (essentially, messages), transfer of custody of a bundle to a recipient relay station at each step of a relay, and return receipts.

Because of limitations on energy resources available for such relays, data rates attainable in a conventional software implementation of the protocol are lower than those needed, at any given reasonable energy-consumption rate. Therefore, a main goal in developing the IONAC is to reduce the energy consumption by an order of magnitude and the data-throughput capability by two orders of magnitude.

The IONAC prototype is a field-programmable gate array that serves as a reconfigurable hybrid (hardware/firmware) system for implementation of the protocol. The prototype can decode 108,000 bundles per second and encode 100,000 bundles per second. It includes a bundle-cache static random-access memory that enables maintenance of a throughput of 2.7Gb/s, and an Ethernet convergence layer that supports a duplex throughput of 1Gb/s.

*This work was done by Jackson Pang, Jordan L. Torgerson and Loren P. Clare of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45584*