National Aeronautics and Space Administration

FY24 Strategic Initiatives Research and Technology Development (SRTD)

Compact Adaptive Optics for Extreme Precision Radial Velocity

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Strategic Focus Area: Extreme Precision Radial Velocities **| Strategic Initiative Leader:** Charles Lawrence

Project Objective:

- Enable a key technology – compact adaptive optics (CAO) – for increasing the discovery of Earth-like exoplanets.
- This will:
  1) radically reduce the size, mass and cost of adaptive optics
  2) shrink the mass and volume of high-resolution spectrographs
  3) enable wide deployment and
  4) increase exoplanet yields

Background:

- Precision radial velocity is key to ground-based exoplanet detection.
- Extreme precision radial velocity (EPRV; RV precision of <10 cm/sec) is the only method for detecting exoEarths.
- High-resolution single-mode spectrographs have the potential to achieve this precision.
- Adaptive optics is required for efficient fiber coupling into these instruments.

Significance to JPL and NASA:

- Ground-based precision radial velocity measurements support NASA science mission objectives for: 1) target identification, 2) follow-up validation and characterization, and 3) mass and orbit determination.
- The need to complete the census of neighborhood stars down to Earth masses, along with follow-up of planetary candidates from NASA transit missions such as *Kepler* and *TESS*, are dramatically increasing the need for ultra-precise Doppler technology
- These NASA missions include Kepler, TESS, JWST, Roman, and future Habitable Worlds Observatory missions

Approach and Results:

- We successfully designed, fabricated, assembled, aligned and tested the compact AO system.
- The key parts of the AO system – the deformable mirror and the Pyramid wavefront sensor - are operational.
- We have closed the loop on the AO system with the realtime software.

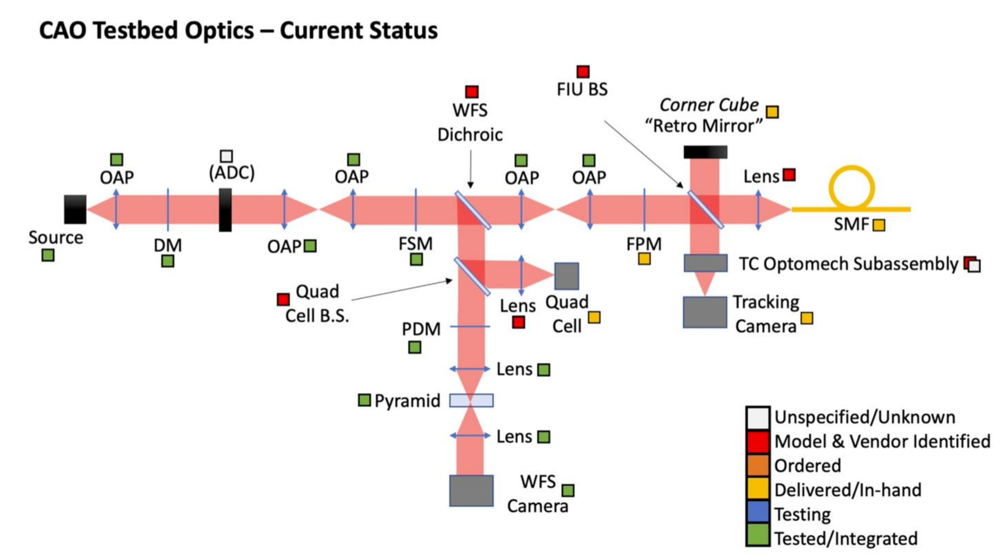

Figure 1. This functional block diagram illustrates the key elements of the Compact AO system and their current status. The adaptive optics relay and the wavefront sensing relay are fully populated and operational.

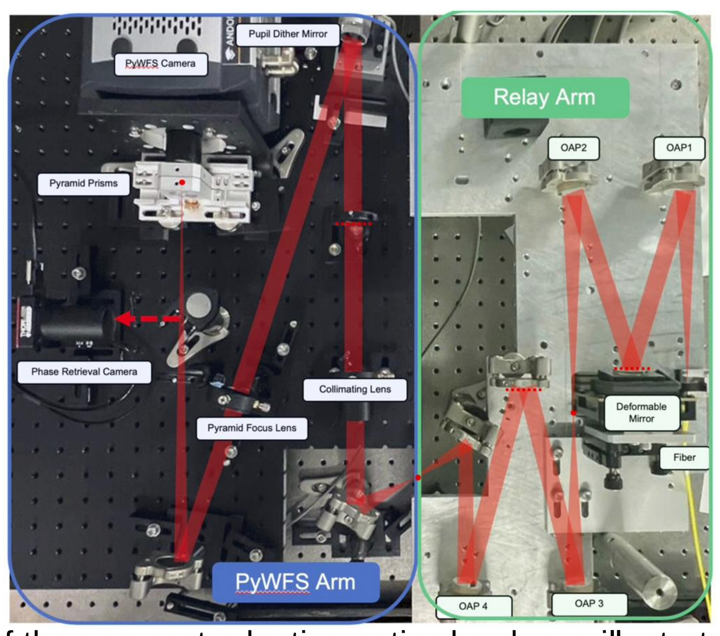

Figure 2. This picture of the compact adaptive optics hardware illustrates the two key operational hardware elements: 1) the adaptive optics relay on the right and 2) the pyramid wavefront sensor relay on the left. Light enters from the single mode fiber on the lower right-hand side and passes through the relay bench first (on the aluminum bench). The light then passes through the pyramid wavefront sensor relay (on the black anodized bench).

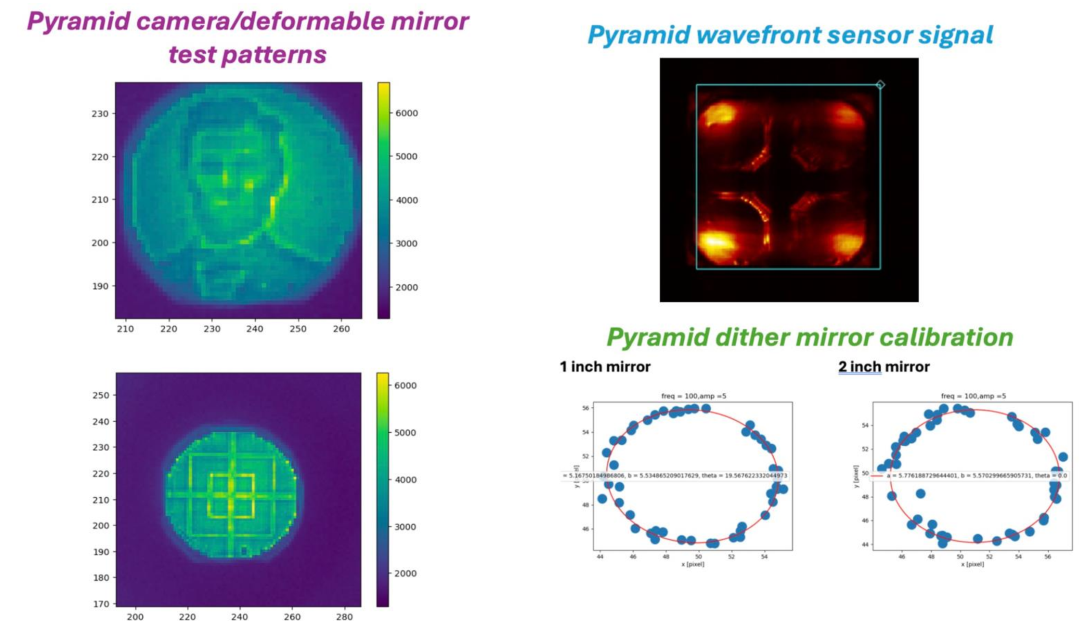

Figure 3. The wavefront sensor camera is a key element of the sensing and control process. The images on the left show that the camera is registered and focused onto the deformable mirror. The top right image highlights the signal after the pyramid optics have been installed and aligned. The lower right figure highlights the work done to calibrate the response of the pyramid sensor dither mirror.

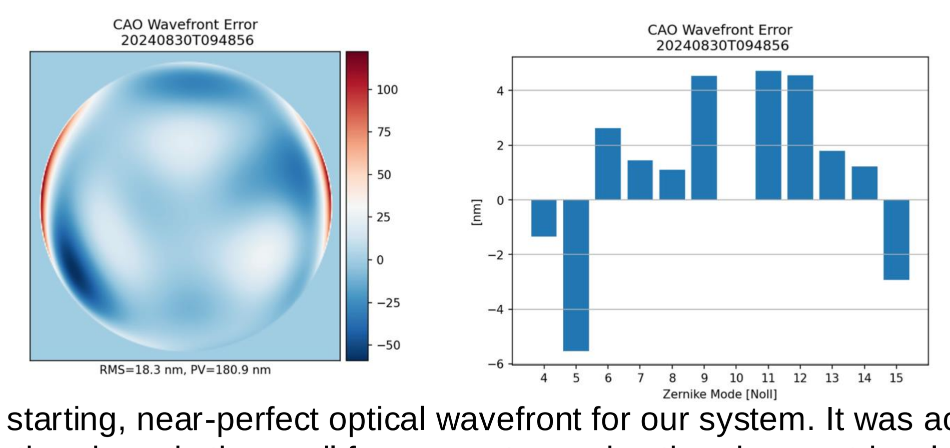

Figure 4. This is the starting, near-perfect optical wavefront for our system. It was achieved by iteratively estimating the phase in the pupil for our system using the phase retrieval system, and then applying corrections to the deformable mirror. The final wavefront is diffraction limited in the visible.

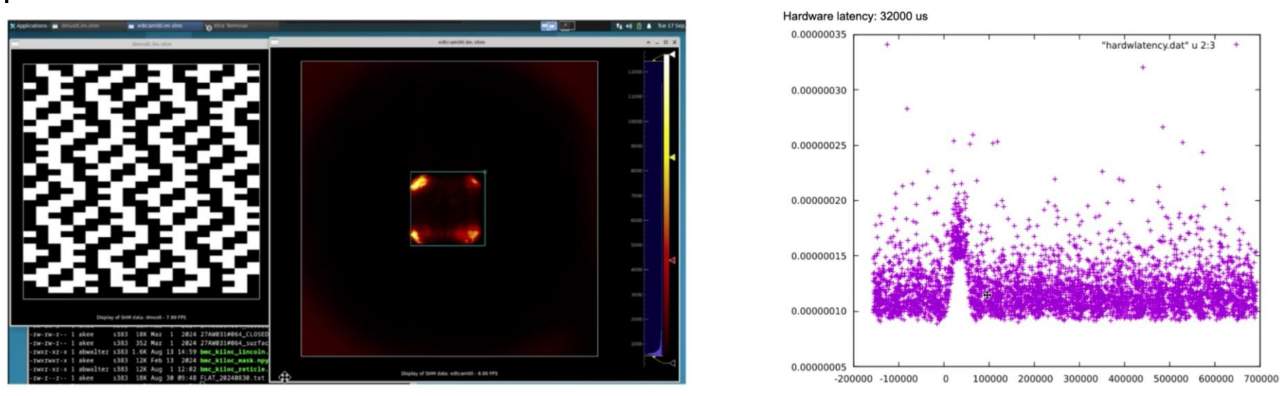

Figure 5. The image on the left shows the realtime operating system as it measures the the response of the system. The black and white pattern is one of the Hadamard patterns that is applied to the deformable mirror. The image on the immediate right is the response of the pyramid wavefront sensor. Inverting the response matrix provides the control matrix. The right-hand image is a measurement of the system latency. It measures the time delay between when the deformable mirror is commanded and the resulting change in intensity is measured on the wavefront sensing camera.

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