National Aeronautics and Space Administration

PALM-3000 and Project 1640 at Palomar Observatory

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Objective

To detect and characterize substellar and young planetary companions to bright stars with contrast ratios of up to 10^{-6} at 0.2 arcseconds separation. With first light in early 2010, this instrument combination will provide a unique capability for 2-3 years, and remain the only such instrument in the northern hemisphere for the foreseeable future.

Key Points

- PALM-3000, a 3368 active actuator upgrade to the Palomar AO system is currently under development at Caltech and JPL, will deliver RMS wavefront error as low as 95 nm on bright stars, with first light expected in early 2010.
- The Project 1640 instrument implements three stages of contrast enhancement:
  1. An apodized coronagraph.
  2. A post-coronagraph wavefront sensor to correct quasi-static wavefront errors.
  3. An infrared IFU to provide chromatic differentiation of residual speckles.
- The combined system is expected to reach contrast ratios sufficient to detect young giant extrasolar planets (~10^{-6} at 0.2 arcseconds separation).

Project Description

PALM-3000 is a 3368 active actuator upgrade to the successful Palomar adaptive optics (AO) system on the Hale 5.1m telescope, currently being designed and built at JPL and Caltech. It will provide high-order AO correction to a suite of instruments which includes the Project 1640 near-infrared coronagraphic integral field spectrograph, designed and built by the American Museum of Natural History, New York. The combination of low wavefront error delivered by PALM-3000, an optimized coronagraph design, and an interferometric calibration system, should enable contrast ratios of up to 10^{-6} to be achieved at as little as 0.2 arcseconds separation.

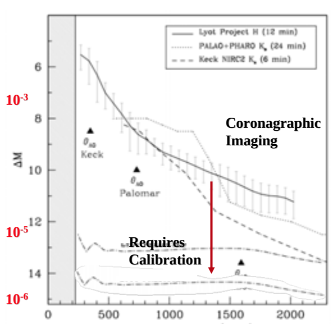

Figure 1: Bright star contrast ratios achievable with various AO systems and instruments. PALM-3000 and Project 1640, using a JPL-built interferometric calibration system, will provide a dramatic improvement in the sensitivity to faint substellar and young planetary companions. (Hinkley *et al*., 2007[2])

PALM-3000

The PALM-3000 AO system is based on a Xinetics photonics module deformable mirror, providing 66x66 actuators on a 1.8 mm pitch, with 2 µm of stroke.

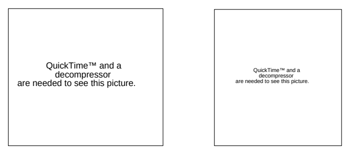

Figure 2: *(left)* Xinetics 66x66 actuator deformable mirror for PALM-3000. *(right)* A single PMN "photonics module" with 11x11 actuators.

A Shack-Hartmann wavefront sensor with selectable pupil sampling (up to 64x64 subapertures across the 5.1 m pupil) will provide high-order wavefront sensing. The 3368 active actuator high-order mirror and 349 actuator "tweeter" DM will be driven at up to 2 kHz using an innovative wavefront processor computer based on a cluster of 16 off-the-shelf graphics processing units.

With high spatial order and low latency, PALM-3000 will deliver an RMS wavefront error as low as 95 nm on bright stars in median conditions, or 88% Strehl in the H band.

Project 1640

The Project 1640 instrument will capitalize on the low wavefront error delivered by PALM-3000, implementing three further stages of contrast enhancement. An apodized coronagraph first suppresses the on-axis starlight subsequent to AO correction. Next, a JPL-built calibration system using starlight intercepted by the coronagraphic stop wil measure the slowly varying component of the residual wavefront error (the quasi-static speckles), and this information will be fed back into the AO control loop. Finally, the back-end instrument, a diffraction-limited, low-resolution ($\lambda/\Delta\lambda$~50) integral field spectrograph, enables candidate substellar and planetary companions to be distinguished from remnant speckles by their distinct chromatic signatures.

Project 1640 will be commissioned in 2008 with the current 241-actuator Palomar AO system. The addition of the calibration system and upgrade to the PALM-3000 system are planned for early 2010.

		PAO + APLC		arcsec	
		0.3	0.5	1	1.5
	5	2.00E-03	0.0008	1.00E-04	3.00E-05
mag	8	2.00E-03	0.0008	1.00E-04	3.00E-05
	12	2.00E-03	0.0008	1.00E-04	3.00E-05
		PAO + APLC+CAL		arcsec	
		0.3	0.5	1	1.5
	5	1.13E-05	5.67E-06	2.83E-06	2.83E-06
mag	8	1.13E-05	5.67E-06	2.83E-06	2.83E-06
	12	2.27E-05	1.13E-05	5.67E-06	5.67E-06
		P3000+APLC+CAL		arcsec	
		0.3	0.5	1	1.5
	5	4.00E-07	2.00E-07	1.00E-07	1.00E-07
mag	8	6.33E-07	3.17E-07	1.58E-07	1.58E-07
	12	1.53E-06	7.67E-07	3.83E-07	3.83E-07

Figure 3: Predicted contrast ratio versus stellar magnitude and separation for the Project 1640 instrument (APLC) at different stages of implementation of PALM-3000 (P3000) and the JPL calibration system (CAL).

Benefits to NASA and JPL

The availability of a high-order AO system and an advanced coronagraphic instrument at an accessible observatory will provide the NASA/JPL community with opportunities for development and testing of many of the components necessary for future ground- and space-based exoplanet detection systems. Obvious examples include:

- Advanced coronagraph designs.
- Innovative control algorithms (eg. predictive control).
- Precision wavefront calibration systems.
- New back-end instrumentation.

The Palomar AO system has to date provided a useful platform for such component development (cf. Serabyn *et al.* 2007[3], Carson *et al.* 2005[4]). PALM-3000 and Project 1640 will only widen the range of possible experiments.

References

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