The PALM-3000 High-Order Adaptive Optics Upgrade for Palomar Observatory

SPIE Astronomical Instrumentation 2008, Marseille

Antonin H. Bouchez[1], Richard G. Dekany[1], John R. Angione[2], Christoph Baranec[1], Matthew C. Britton[1], Khanh Bui[1], Rick S. Burruss[2], John L. Cromer[1], Stephen R. Guiwits[2], John R. Henning[3], Jeff Hickey[3], Daniel L. McKenna[3], Anna M. Moore[1], Jennifer E. Roberts[2], Thang Q. Trinh[2], Mitchell Troy[2], Tuan N. Truong[2], Viswa Velur[1]

1. California Institute of Technology
2. NASA Jet Propulsion Laboratory
3. Palomar Observatory

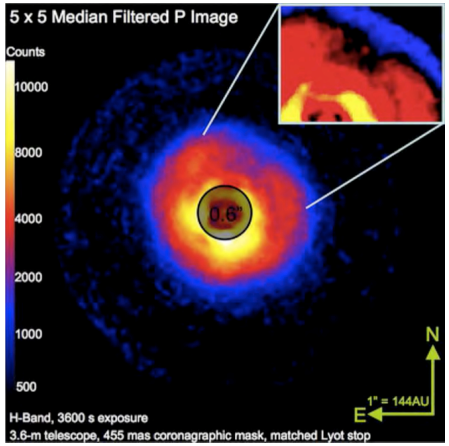
Outline

- Science case
- Instrument concept
- Expected performance
- Designs of select subsystems
- Science instruments

Science Case

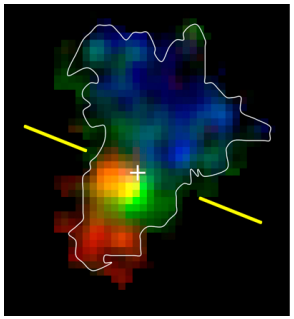
Science Drivers

- Galactic
  - Hot, young exo-Jupiter studies.
  - High-contrast debris disks with LGS.
  - Mass/luminosity of pre-main sequence binaries.



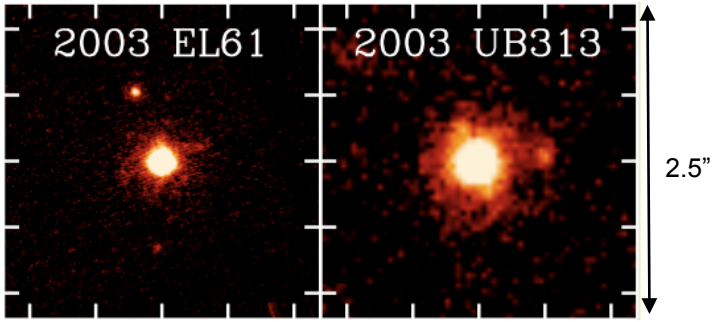
Oppenheimer *et al.*, AJ 679, 2008

- Extragalactic
  - M-σ relation to z = 0.15
  - Dynamics of z = 1.0-1.7 galaxies.



Genzel *et al.*, Nature 442, 2006

- Solar system
  - Io surface geology.
  - Multiplicity of Kuiper Belt objects.
  - Surface minerology of large asteroids.



Brown *et al.*, ApJ 639, 2006

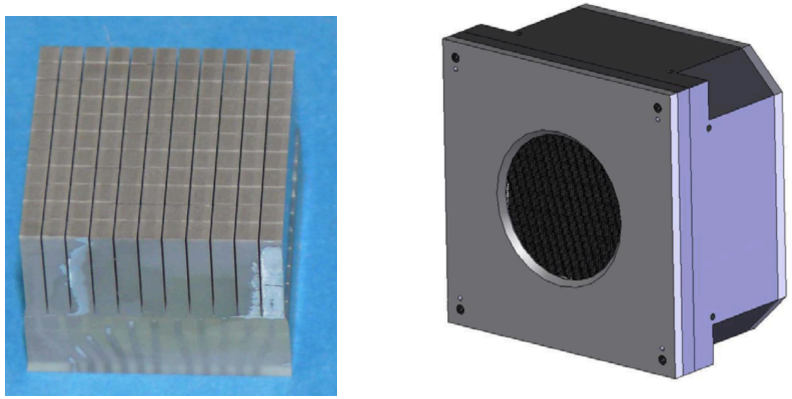
PALM-3000 Capabilities

New Capabilities

- Precision near-IR photometry and astrometry based on excellent PSF stability and knowledge.
- High contrast imaging at both visible and near-IR.
- High spatial resolution spectroscopy of resolved objects.
- High sensitivity faint-object visible light imaging.

Enabling technologies

- High actuator count, small pitch (1.8 mm), deformable mirrors.
- Low-cost, high-performance compute engines.



Xinetics Photonics module and 66x66 actuator mirror.

NVIDIA GeForce 8800 graphics processor

PALM-3000 Instrument Concept

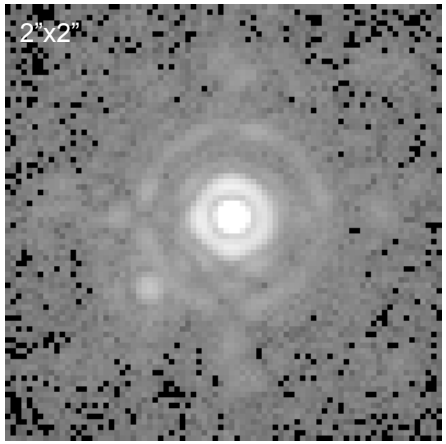
- Add a Xinetics 3368 active actuator “tweeter” DM
  - 66 x 66 actuators on 1.8 mm pitch (4.55” ∅)
  - 2 μm stroke
- Retain current Xinetics 349 active actuator DM as woofer.
  - 20 x 20 actuators on 7.0 mm pitch (5.52” ∅)
  - 5 μm stroke
- 64x64 subaperture high-order WFS.
- Infrared tip/tilt sensor.
- Wavefront processor computer.
- Supervisory control & user interface.
- New instruments for high contrast and diffraction-limited visible science.

- Reuse much of current PALMAO NGS/LGS system
  - Optical bench, stimulus unit.
  - Relay optics (Off-axis parabolas, tip/tilt mirror).
  - Low-order wavefront sensor.
  - Laser beam transfer optics, launch telescope, software.
  - AO bench handling fixtures.

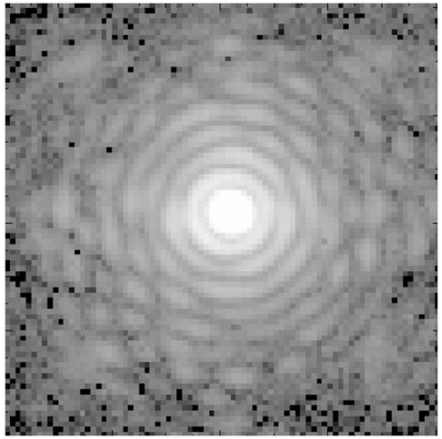
PALM-3000

Predicted Performance: NGS Strehl

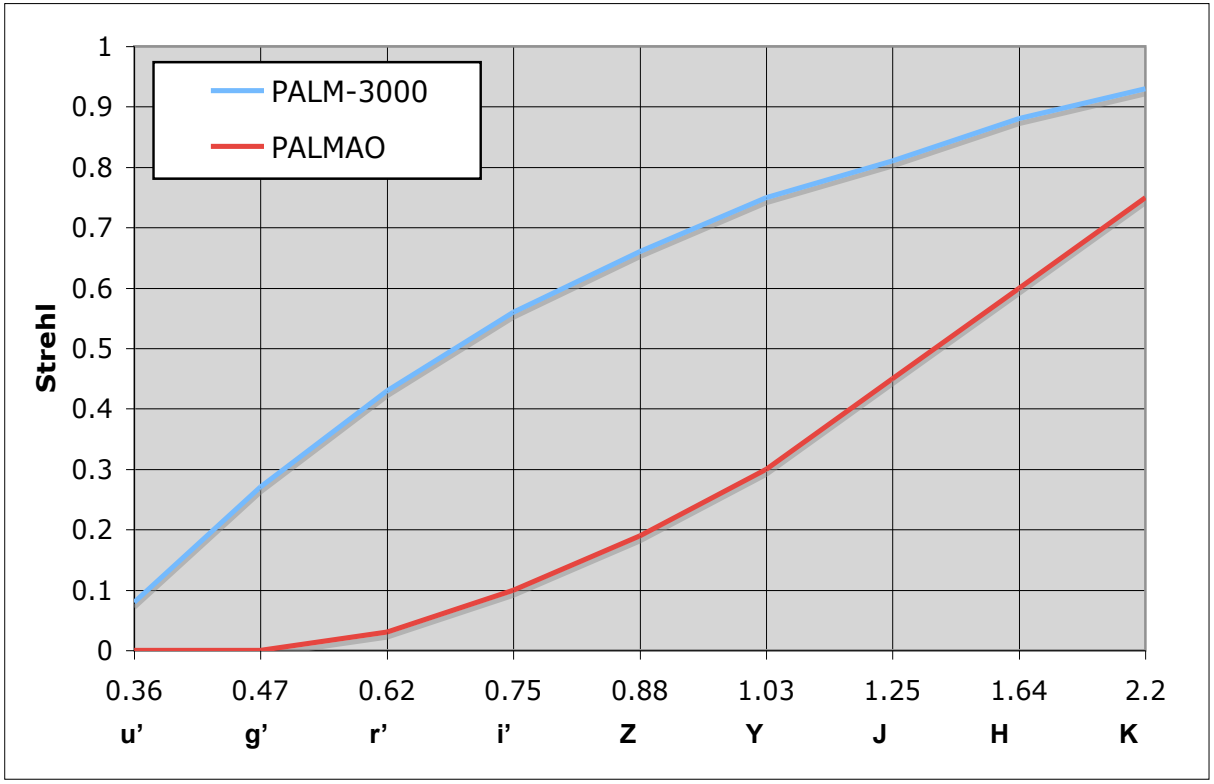
PHARO images



PALMAO K_s, Strehl = 0.75
r_0 = 11 cm



PALMAO + WCS Brγ Strehl = 0.94
from Serabyn *et al.* AJ 658, 2007.

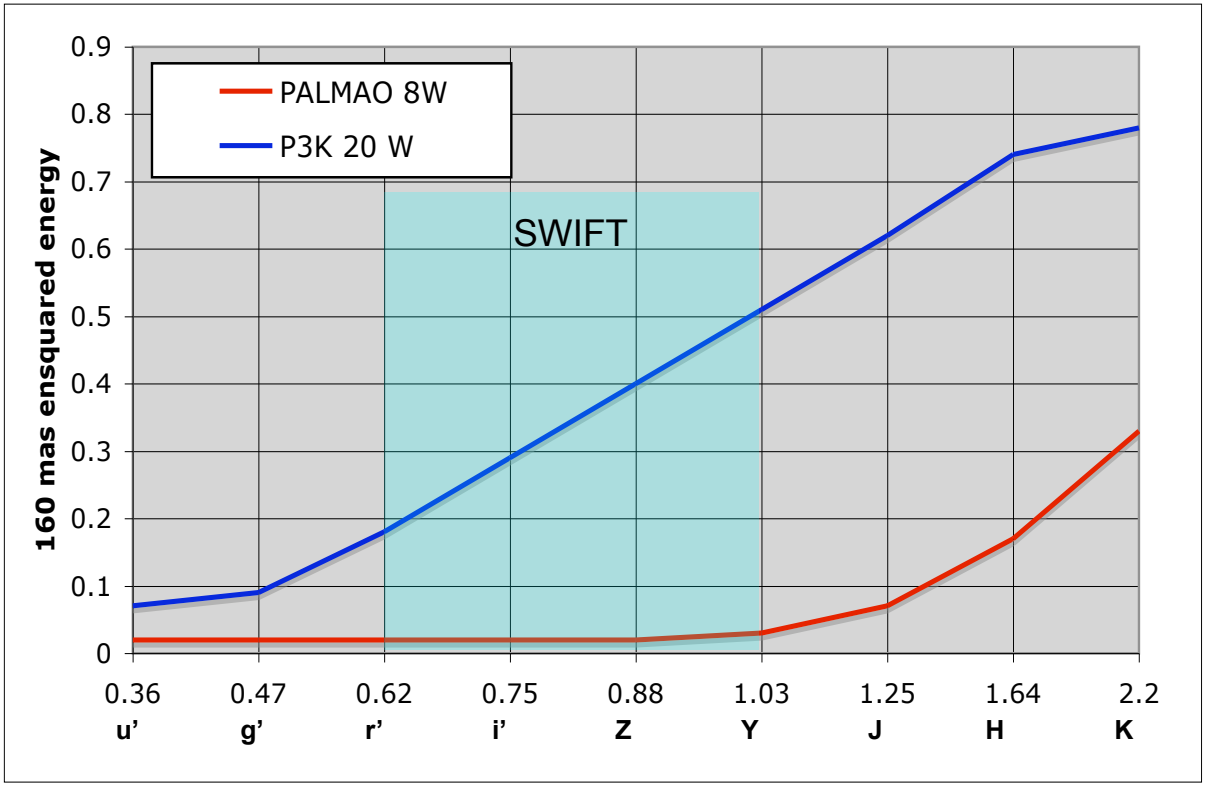


Science case: Young star companion survey

- Instrument: Project 1640
- NGS V=6
- 30º zenith angle
- r_0 = 9.2 cm

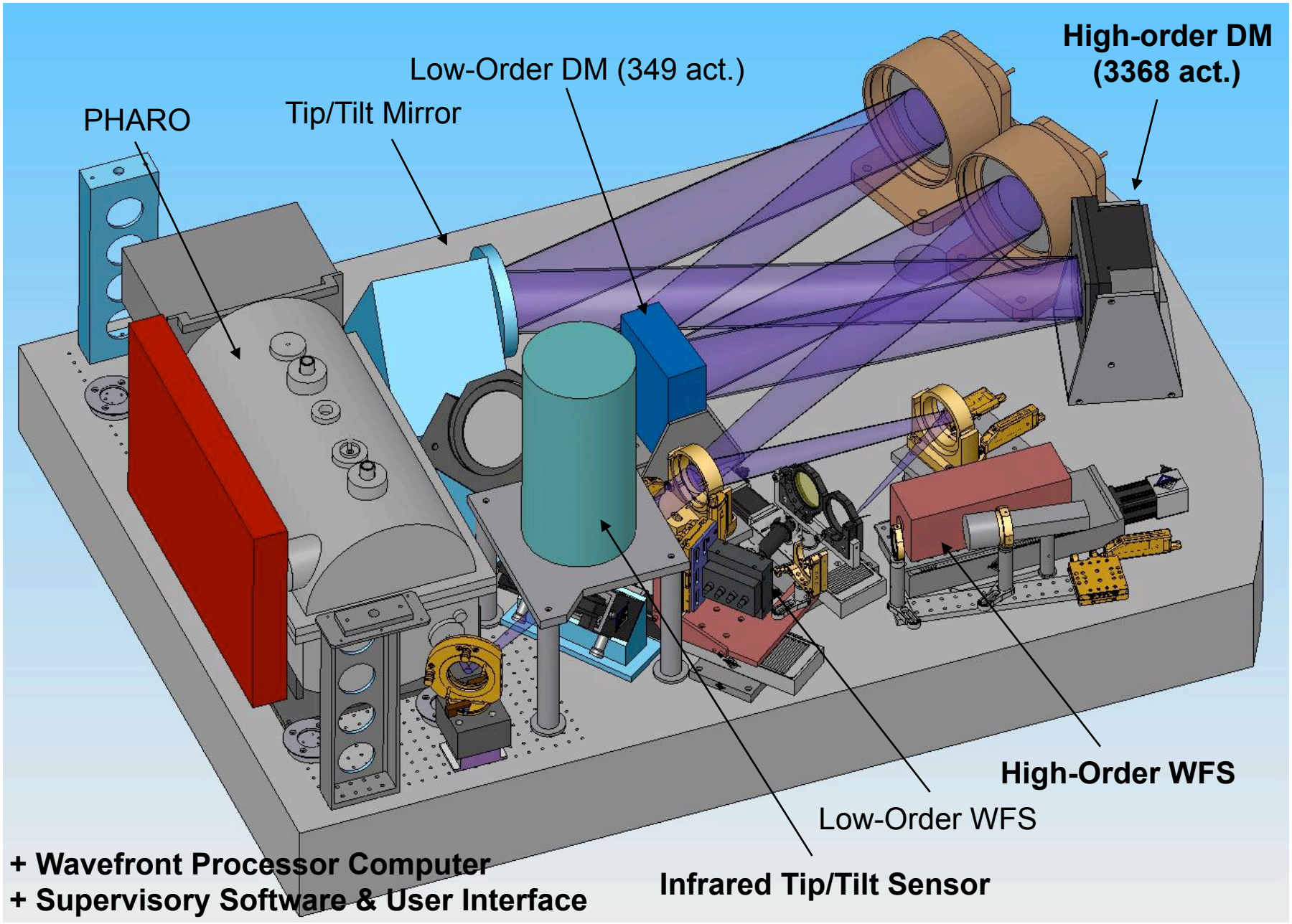
PALM-3000

Performance: LGS Ensquared Energy



Science case: Dynamics of z=1 galaxies

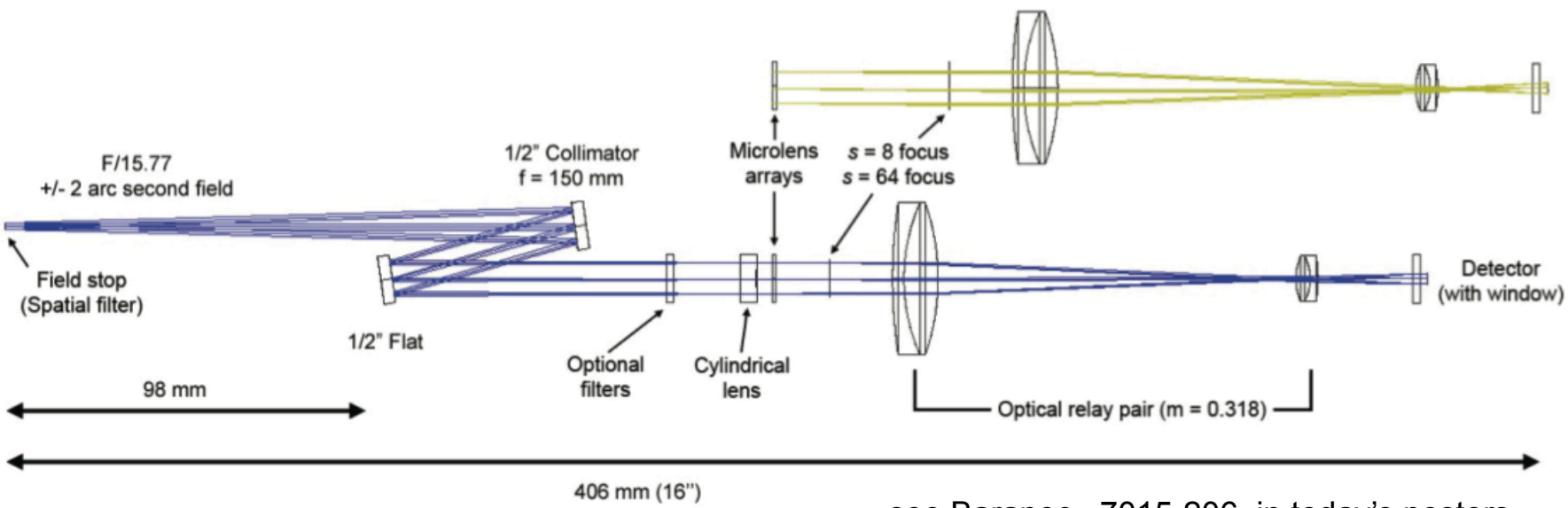
- Instrument: SWIFT
- 5% sky coverage at *b*=30 → V=14.9 NGS at 60.0”
- 5º zenith angle
- r_0 = 9.2 cm


High-order DM
(3368 act.)
Low-Order DM (349 act.)
Tip/Tilt Mirror
PHARO
High-Order WFS
Low-Order WFS
Infrared Tip/Tilt Sensor
+ Wavefront Processor Computer
+ Supervisory Software & User Interface

PALM-3000

High-Order Wavefront Sensor

- Shack-Hartmann sensor using E2V CCD50 (128x128, 24 μm pixels, 16 amplifiers, 3 kHz frame rate).
- Selectable pupil sampling: 8x8, 16x16, 32x32, 64x64.
- Stringent requirement on pupil registration (10% of a subaperture).
- Spatial filter at entrance aperture (minimum 0.48” = 190 μm)



see Baranec , 7015-206, in today’s posters.

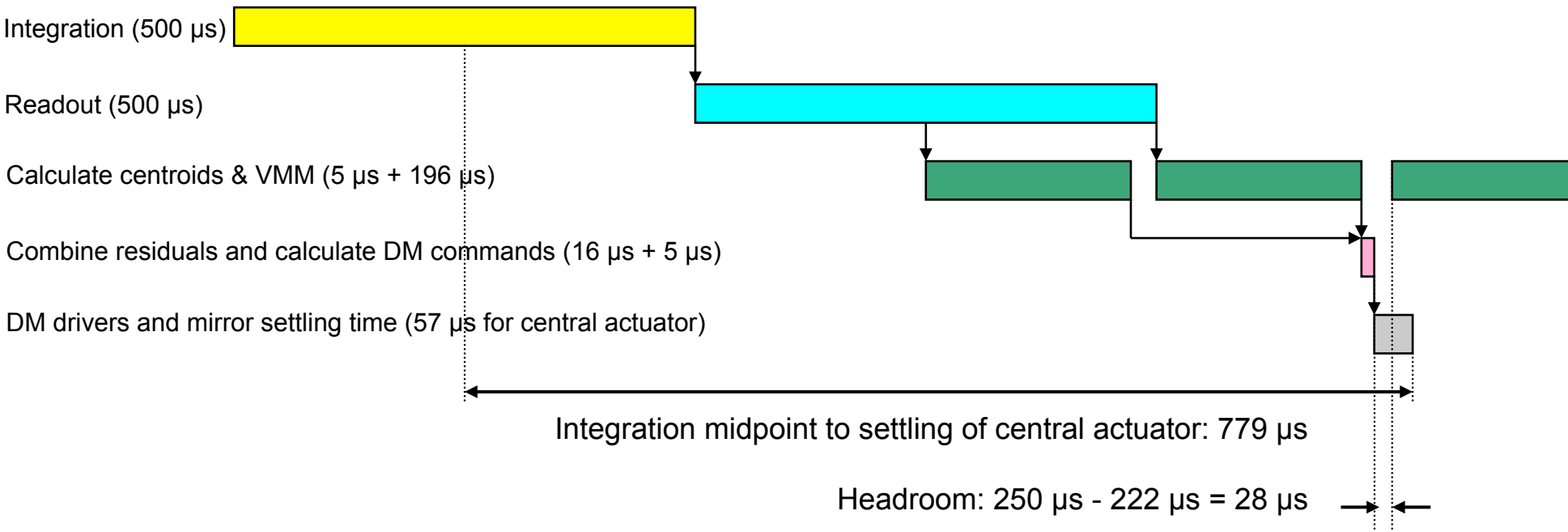
Wavefront Processor Computer

- Specified to allow full vector matrix multiplication at 2 kHz.
  - 3719 x 4096 element reconstructor
  - Expect to support 3 kHz with more efficient algorithms.
- Chosen architecture: 16 NVIDIA 8800 GTX graphics cards, each processing 1/16 of camera pixels.
- GPUs housed in 8 PCs, connected through a Quadrics QsNet 16-port switch (14.4 Gb/s bandwidth).
- Additional PCs in cluster:
  - Central node to combine wavefronts, & process LGS sensors.
  - Telemetry recorder (& 10 Tb RAID)

PALM-3000

Wavefront Processor Performance

2000 Hz framerate full VMM processing timeline



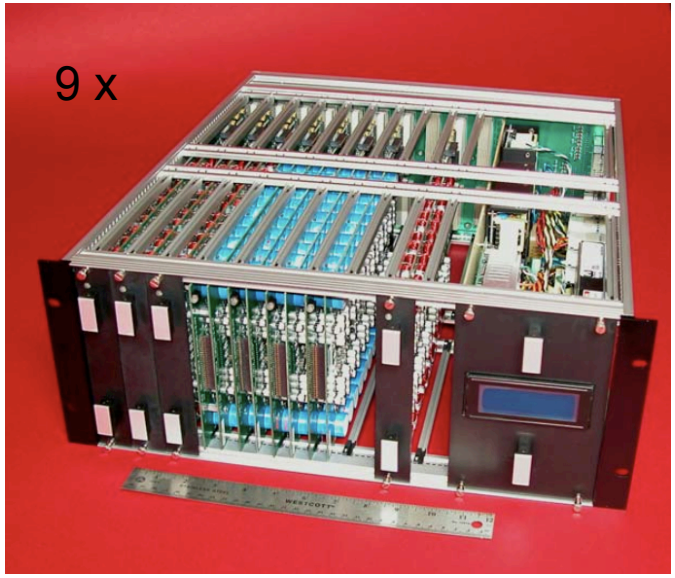
see Truong *et al.*, 7015-125.

DM Control issues

- Implementing two woofer-tweeter control algorithms:
  - Modal division between DMs.
  - Offload from tweeter to woofer.

- Investigating how to control platescale variability due to low-order modes on woofer DM not located at the pupil.
  - Particular concern due to large stroke used to correct Hale primary.
  - Attempting to keep woofer conjugate within 1.5 km of ground.

- Still considering how to address heat generated by DM electronics.
  - Possibility of locating them off the telescope.

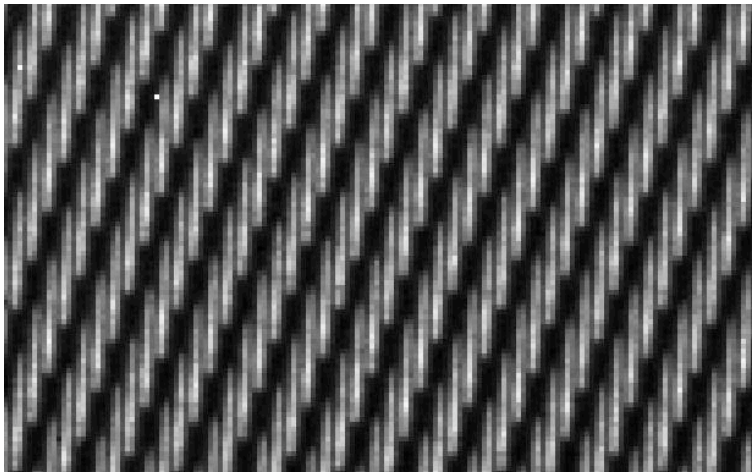


PALM-3000

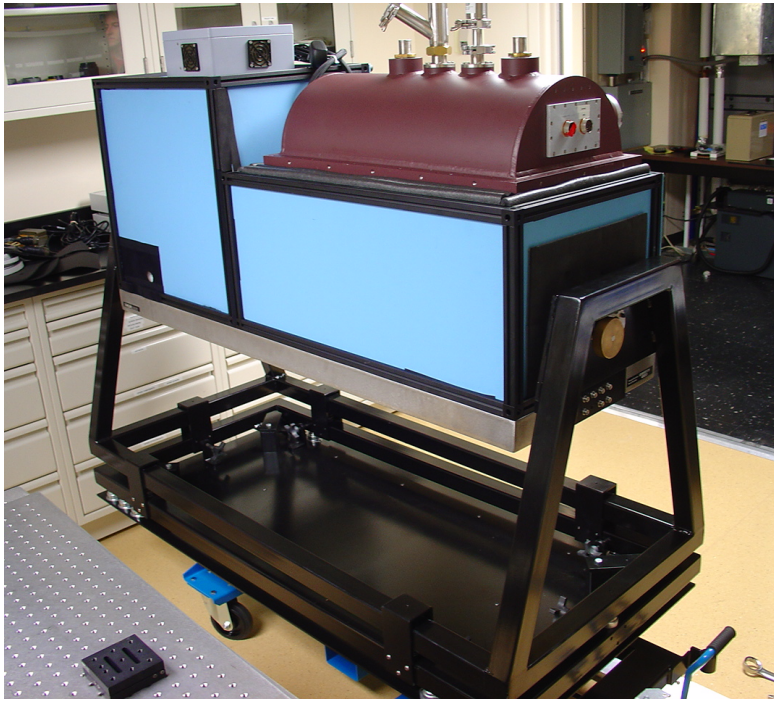
Instruments: Project 1640

- PI: Ben Oppenheimer, American Museum of Natural History
- Apodized Lyot coronagraph with a low-resolution ($\lambda/\Delta\lambda$=30) J-H band integral field spectrograph back-end.
- Commissioning July 2008.
- Expected contrast levels for bright stars at 1.0” radius:
  - PALMAO 8×10^{-4}
  - P3K 5×10^{-6}
  - P3K + JPL Cal 2×10^{-7}

see Hinkley *et al.*, 7015-44.



Raw spectra of a broadband calibration source



Project 1640 in the lab at AMNH

Instruments: SWIFT

- PI: Niranjan Thatte, University of Oxford
- High-efficiency visible light integral field spectrograph
  - Glass image slicer
  - Deep depletion LBNL 2048 x 4096 pixel CCDs.
  - $\lambda/\Delta\lambda$ ~ 3500 over 650 - 1050 nm.
  - 44x89 spaxials with 3 scales: 0.08”, 0.16”, 0.24”.
- Commissioning in fall 2008.

see Thatte *et al.*, 7014-203.

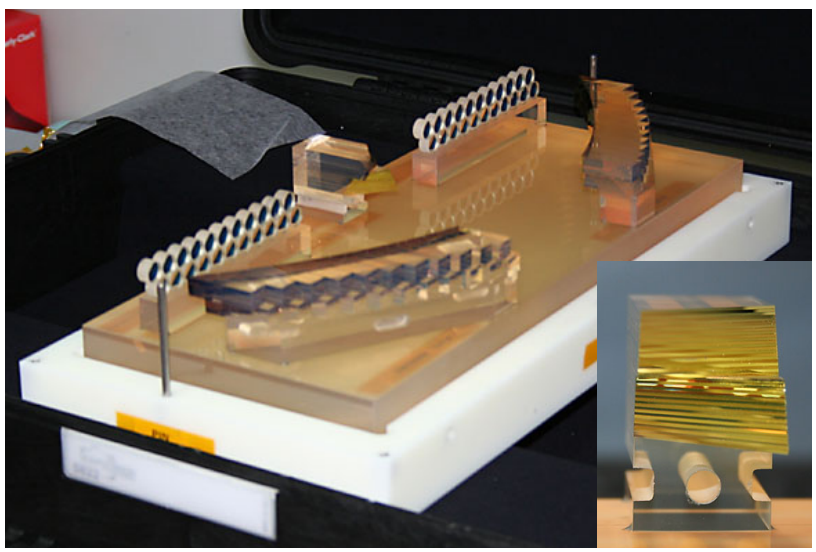
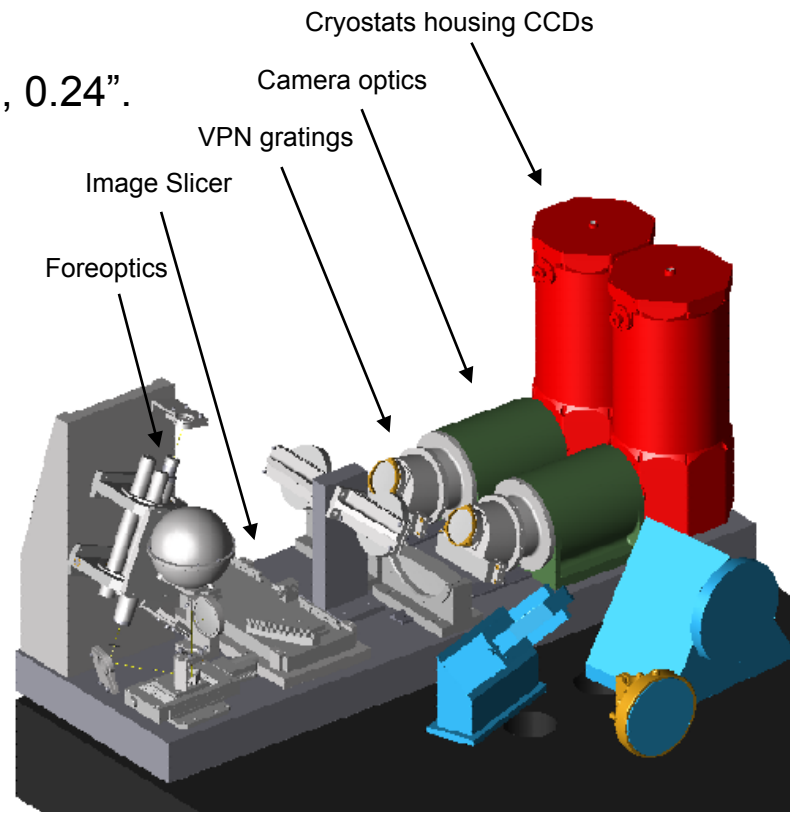


Image slicer assembly



Model of the completed instrument

Instruments: PHARO and 888Cam

PHARO

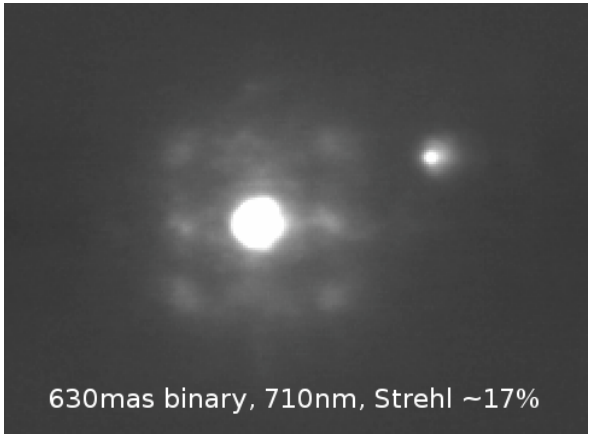
- PI: Tom Hayward, Cornell University
- Near-Infrared camera and grism spectrograph, with Lyot coronagraph.
- Commissioned on PALMAO system in 1998.
- Routinely used as platform for tests of novel coronagraphic masks and other techniques.

PHARO installed on the PALMAO system

888Cam

- Concept for a fast framerate visible imager for PALM-3000.
- 1024 x 1024 pixel Andor camera, nyquist sampled at H-alpha.
- Imaging at up to 50 Hz over subarrays.

see Law *et al.*, 7015-89.



PALMAO & LuckyCam
(Law *et al.*, ApJ 805, 2008)

Schedule

	Commission
• Phase 0: New science instruments	summer 2008
– Project 1640	
– SWIFT	
• Phase 1: High-order NGS upgrade	April 2010
– 3368 actuator deformable mirror	
– 64 x 64 high order wavefront sensor	
– New wavefront reconstructor computer	
– New supervisory control software & user interface.	
• Phase 2: Improve LGS performance & sky coverage	2011
– 20W class sodium laser	
– Infrared tip/tilt sensor	
– Upgraded low-order NGS wavefront sensor.	

Conclusions

- PALM-3000 will be first *extreme* AO system fielded for astronomy.
- High contrast capability likely to remain unmatched in northern hemisphere for some time.
- Diffraction-limited visible light imaging and IFU spectroscopy likely to open a new realm of AO science.