



Phase Retrieval Camera Testing of the Ball AMSD Mirror

*Catherine Ohara, Scott Basinger, David Cohen, Jessica Faust,
Joseph Green, Andrew Lowman, David Redding*
Jet Propulsion Laboratory, California Institute of Technology

Jay Carpenter, Ron Eng, Jeff Kegley
Marshall Space Flight Center

Joe Geary, James Hadaway, Pat Reardon, Ted Rogers
University of Alabama, Huntsville

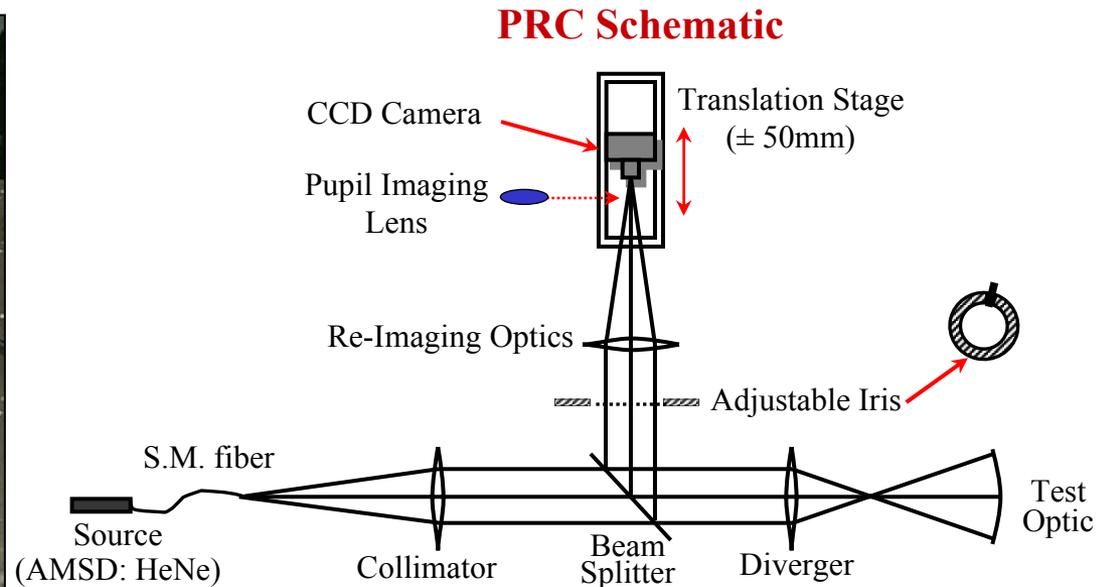
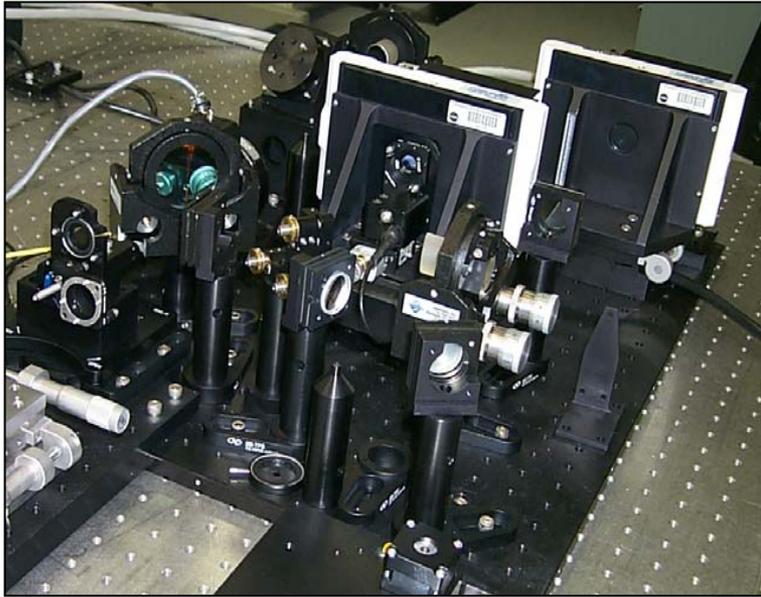
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Image-based Wavefront Sensing for JWST



- JWST will utilize *image-based* wavefront sensing techniques to align its optics and achieve diffraction-limited performance at $2\ \mu\text{m}$
 - The final step in the alignment uses focus-diverse phase retrieval, in which defocused PSF measurements are acquired with the science camera to compute the exit-pupil wavefront
 - Computed wavefront errors are used to determine the necessary corrections to *fine phase* the primary mirror segments
- Phase Retrieval Camera (PRC) encapsulates the JWST fine phasing process within a portable, self-contained instrument
 - Designed for optical testing in high-jitter environments
 - Previous experiments have demonstrated that the PRC compares to a ZYGO to within 4-nm rms wavefront [J. Green, SPIE Waikoloa 2002]
 - Here we present our recent measurements of the Ball AMSD mirror and compare them to the measurements made with the Instantaneous Phase Interferometer (IPI)

The Phase Retrieval Camera

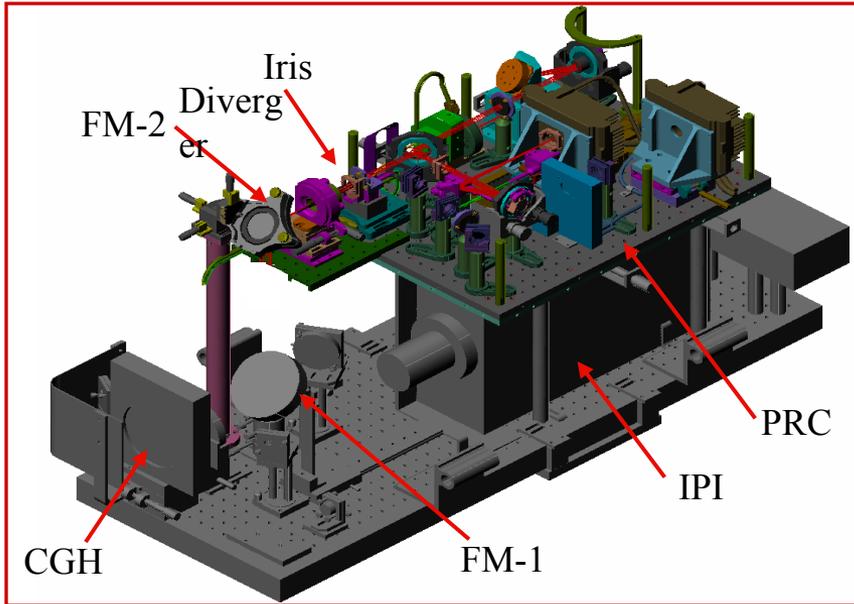


- Test optic is imaged onto adjustable iris (pupil) for telecentricity
- Camera on translation stage provides defocused images for WFS
- High-speed shutter to freeze jitter
- Pupil imaging lens
- Flip-in flat mirror for calibration
 - Internal WFE $< 0.01 \lambda_{633}$ rms, measured both before and after delivery to XRCF

AMSD Experiment Description

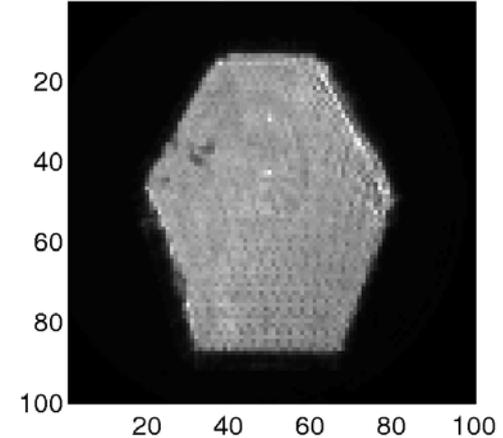


PRC Installation at XRCF



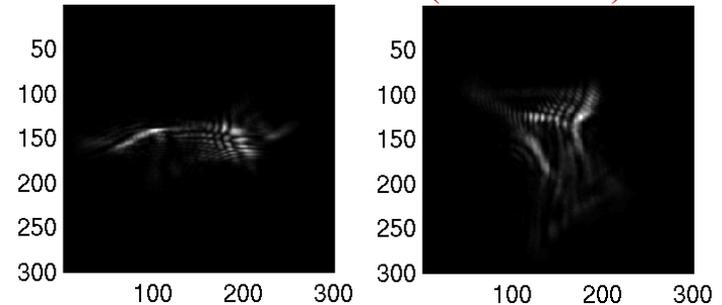
- PRC Installation
 - Mounted above the IPI on 4 posts
- PRC Operation
 - Short exposure times (0.3 to 1 msec) due to high-jitter XRCF environment
 - To maintain high SNR in images, camera defocus constrained to +/-30mm
 - Several co-added frames at each defocus setting

Pupil Image

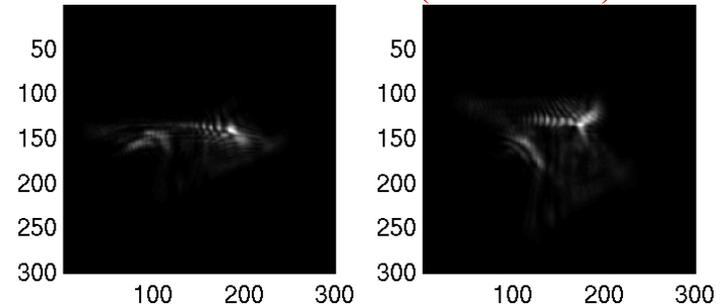


Focus-Diverse PSF Images

Defocus = $\pm 30\text{mm}$ (± 3.8 waves)



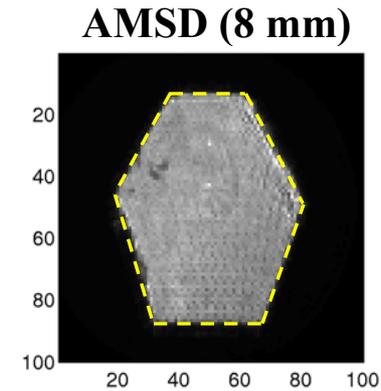
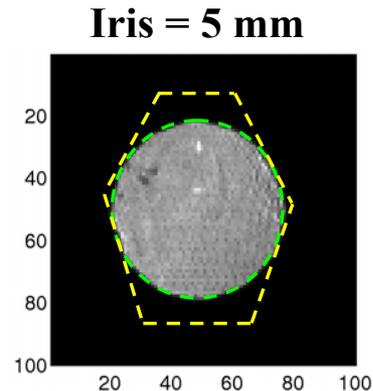
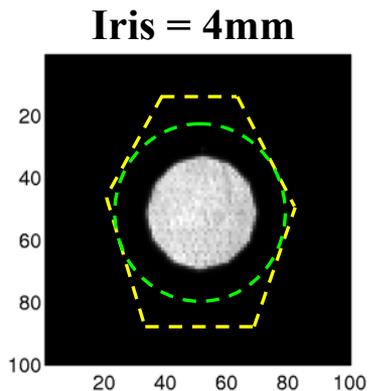
Defocus = $\pm 15\text{mm}$ (± 1.9 waves)



AMSD Wavefront Sensing



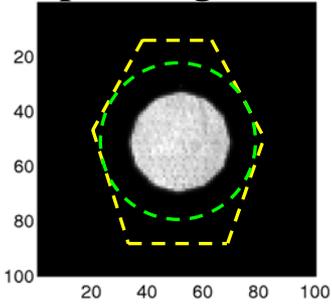
- High-Dynamic Range WFS
 - AMSD aberrations were significantly larger than the level of inducible-focus in the PRC
 - While it is beneficial (but not necessary) to acquire data images that are dominated by the induced focus aberration, one can instead use an *a priori* or “starting point” phase map to reduce dynamic range required by the algorithm
- *A priori* phase map using the PRC variable aperture (iris)
 - Stop down the system; measure the phase over a smaller, less-aberrated region of the mirror
 - Extrapolate the stopped-down result to the full pupil size to generate an *a priori* phase map
 - Phase retrieval algorithm computes the *difference* between the starting map and the actual wavefront
- Other approaches also possible
 - Prescription retrieval to compute low-order aberrations
 - Model the figure errors induced by gravity



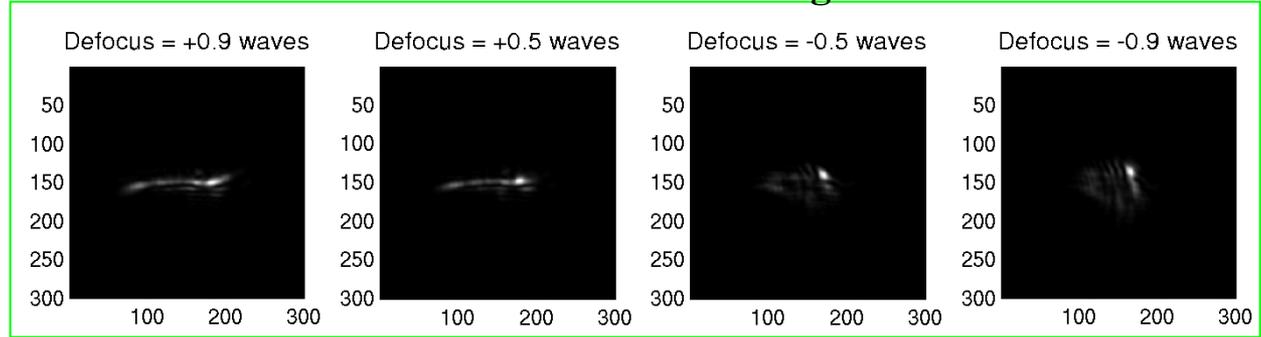
AMSD: Stopped Down Aperture (55K)



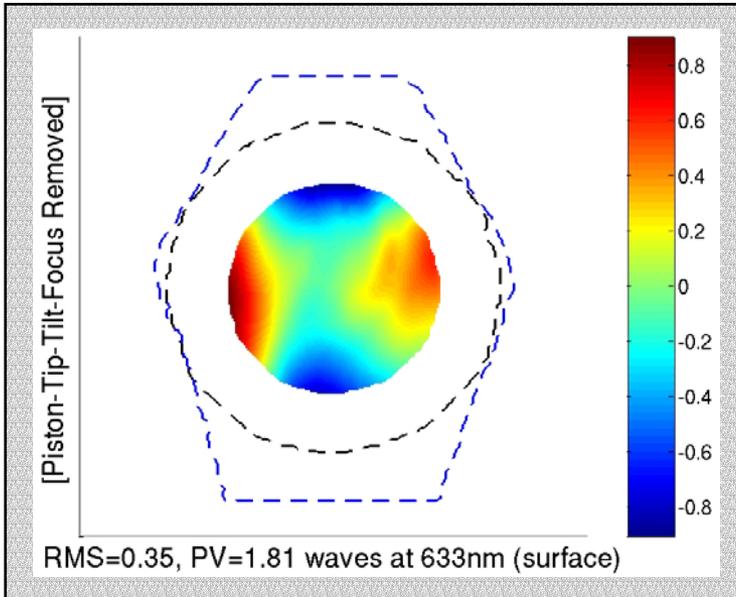
Pupil Image: 4mm



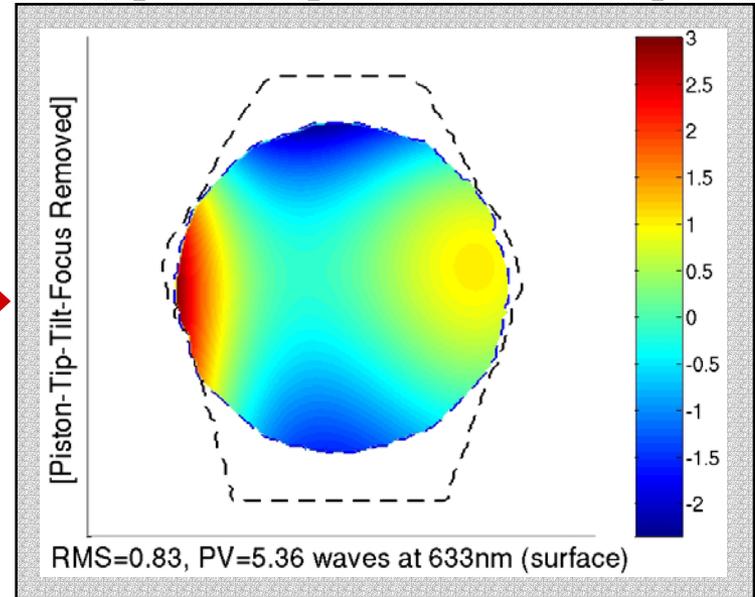
Focus-Diverse PSF Images



**PRC Surface Map (Iris=4mm)
(no *a priori* map used)**



**Extrapolation to 5mm size
(*a priori* map for next WFS step)**

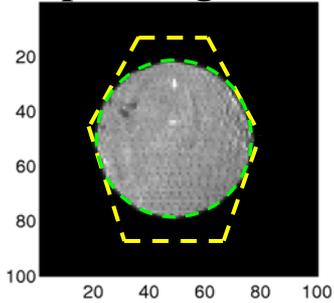


(Piston-tilt-power removed)

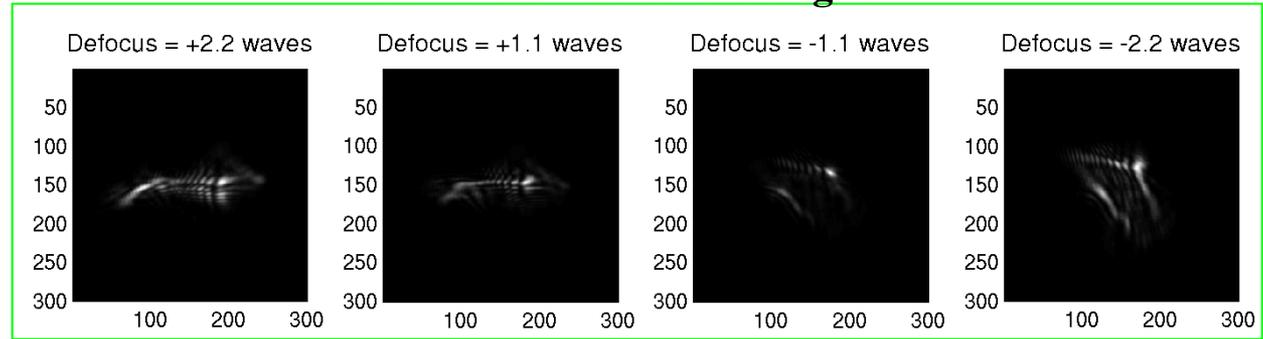
AMSD: Stopped Down Aperture (55K)



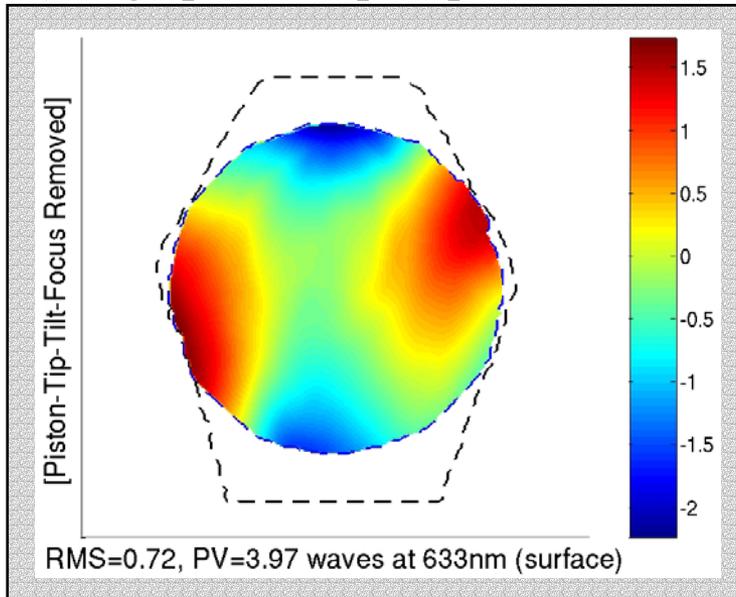
Pupil Image: 5mm



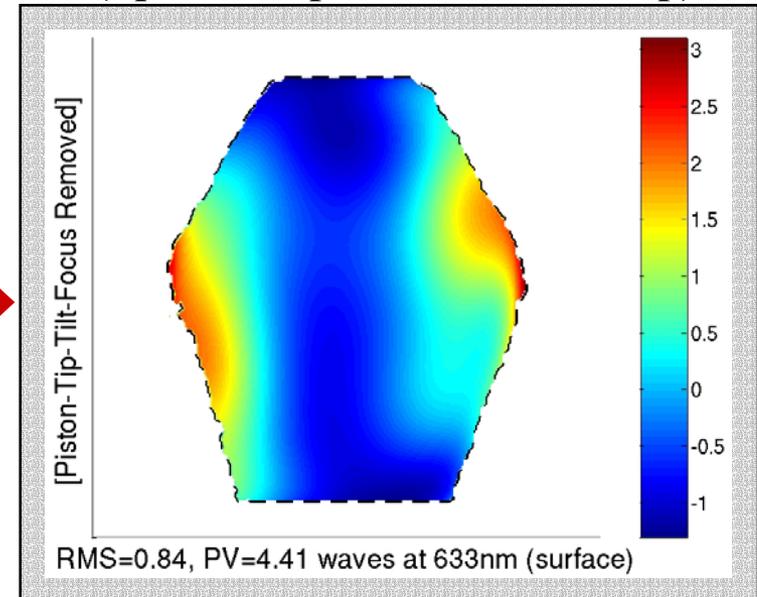
Focus-Diverse PSF Images



PRC Surface Map (Iris=5mm) (using *a priori* map on previous slide)



Extrapolation to full hexagon (*a priori* map for final WFS step)

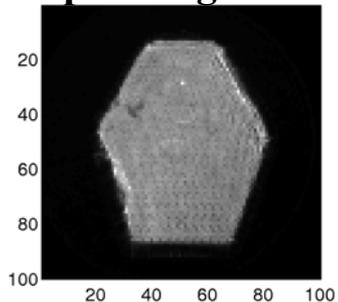


(Piston-tilt-power removed)

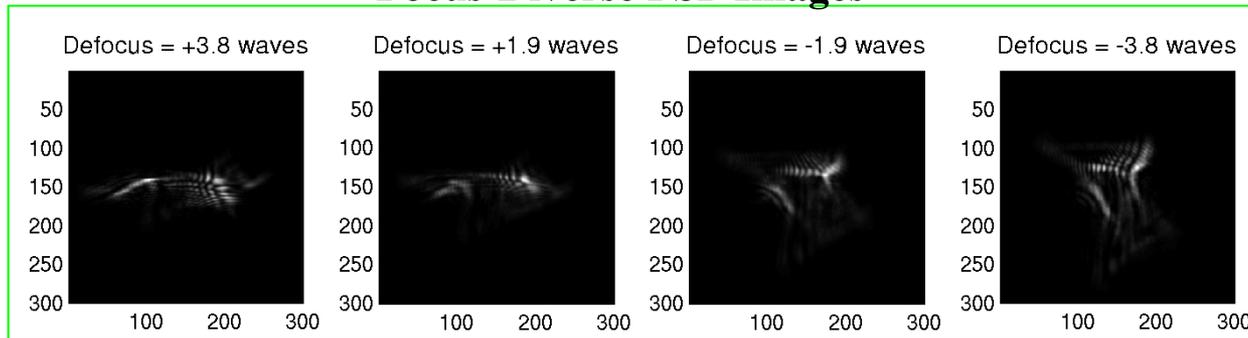
AMSD: Full Aperture (55K)



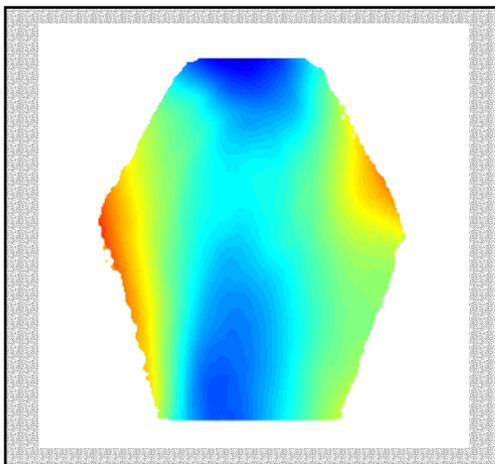
Pupil Image: 8mm



Focus-Diverse PSF Images

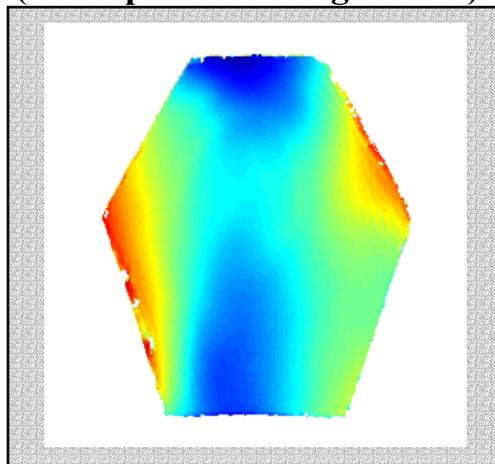


PRC



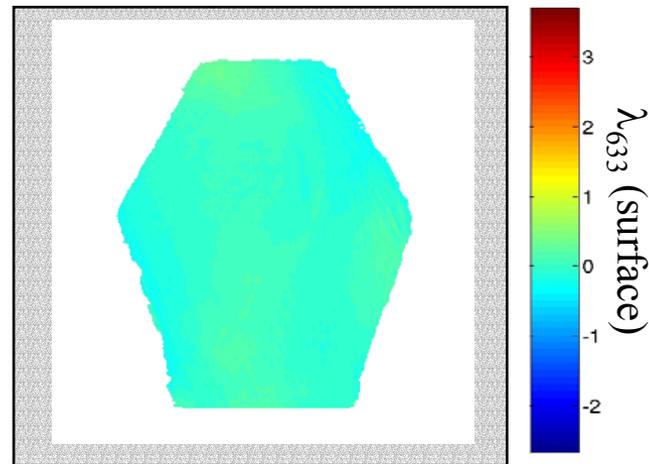
RMS=0.86, PV=4.7 waves

IPI (resampled to PRC grid-size)



RMS=0.96, PV=6.4 waves

PRC minus IPI



RMS=0.10, PV=0.8 waves

(Piston-tilt-power removed)

PRC Comparison to IPI

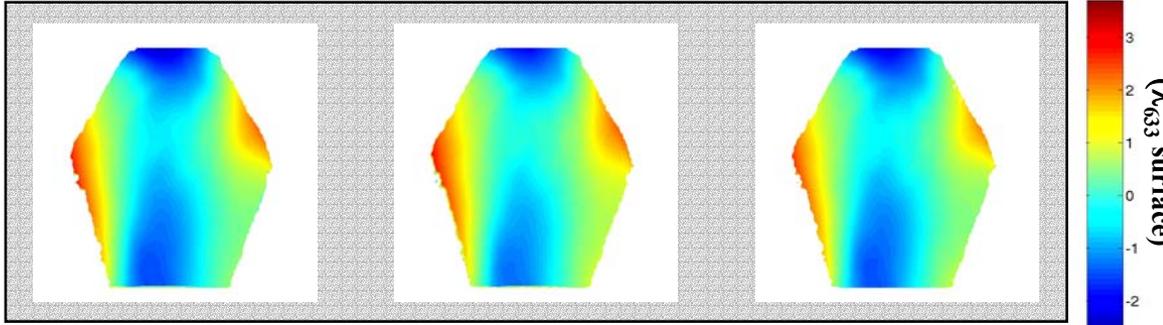


30 Kelvin

45 Kelvin

55 Kelvin

PRC



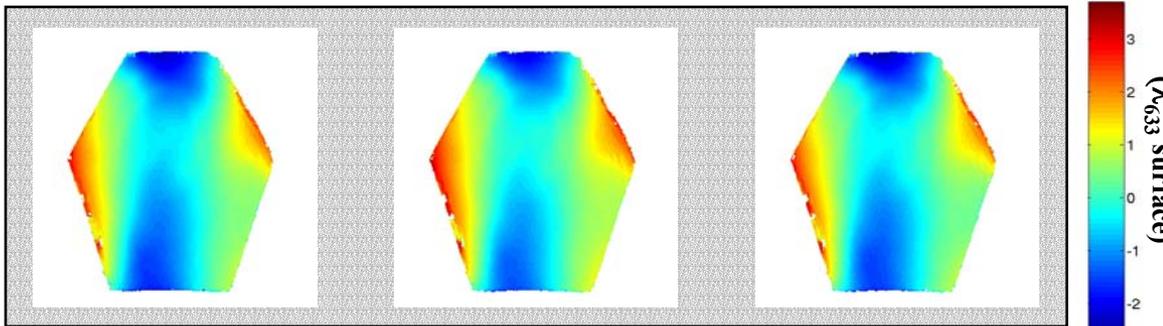
RMS=0.96, PV=5.2

RMS=0.91, PV=4.9

RMS=0.86, PV=4.7

- PRC at 30/45/55 K
 - RMS ~ 0.9 waves
 - PV ~ 4.9 waves

IPI



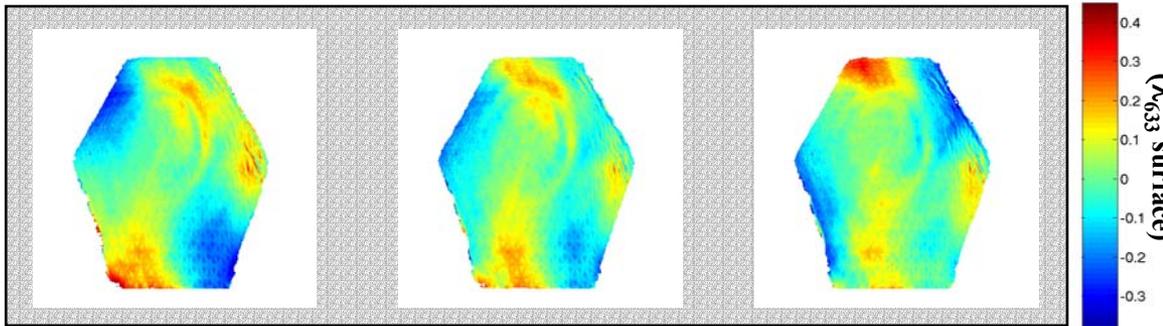
RMS=1.02, PV=6.7

RMS=1.01, PV=6.6

RMS=0.96, PV=6.4

- IPI at 30/45/55 K
 - RMS ~ 1.0 waves
 - PV ~ 6.6 waves

PRC minus IPI



RMS=0.12, PV=0.9

RMS=0.09, PV=0.7

RMS=0.10, PV=0.8

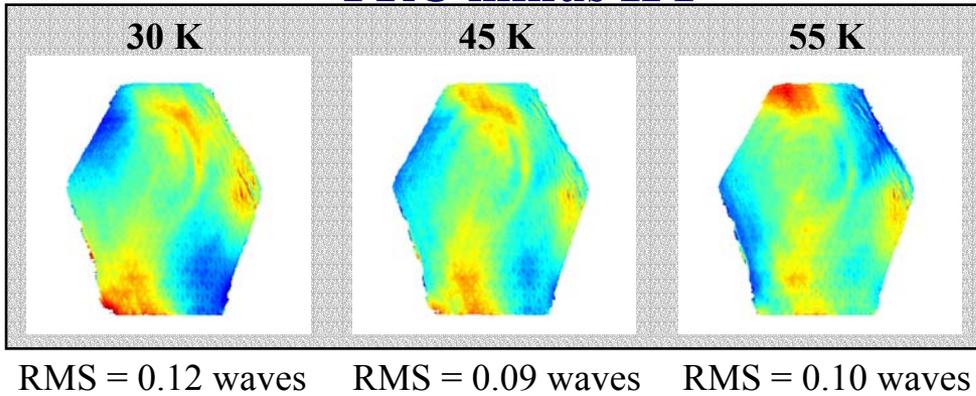
- Differences suggest a systematic error between the PRC and IPI (~0.1 waves rms)

(Piston-tilt-power removed)

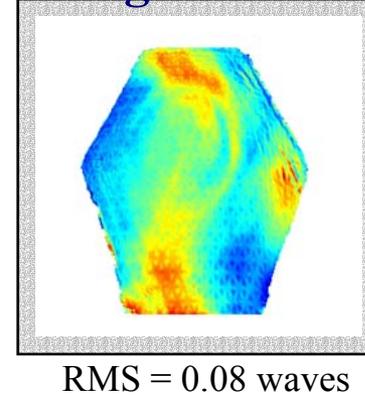
Comparison of PRC/IPI Differences



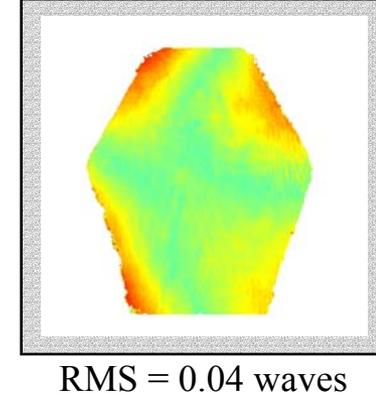
PRC minus IPI



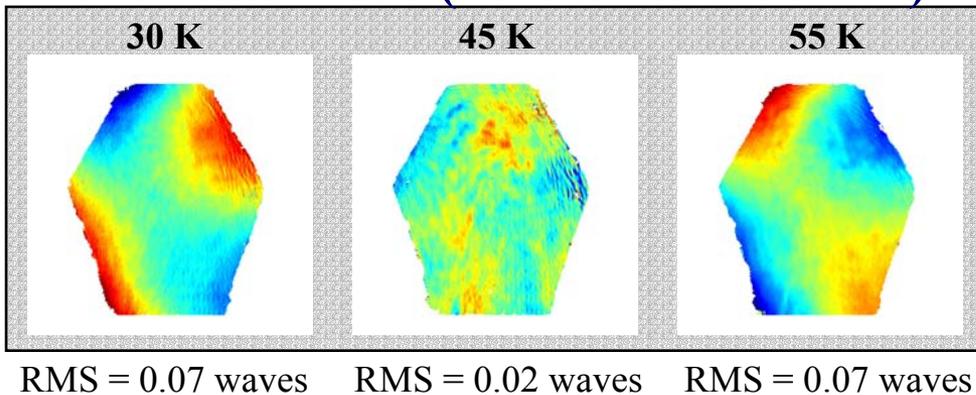
Average Difference



Deviation

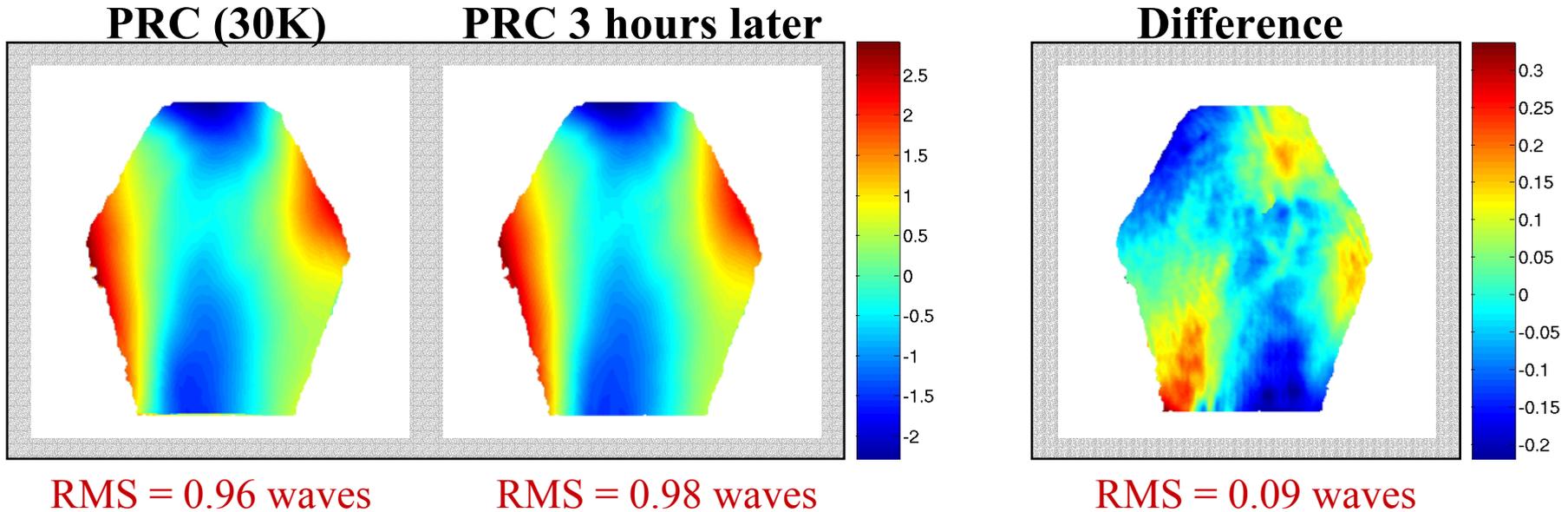


PRC minus IPI (with mean removed)



- Average difference may indicate a static, systematic error between the PRC and IPI
 - Alignment (i.e., PRC slightly rotated with respect to IPI?)
 - Non-common path optics
 - Different spatial bandwidths

AMSD Alignment/Figure Drift



- PRC measurements taken 3 hours apart illustrate the dynamic changes in the system alignment and/or mirror figure
- These variations are on the level of the observed PRC minus IPI differences

Closing Remarks



- In this experiment, we measured the Ball AMSD cryogenic surface figure using the same image-based wavefront sensing techniques that will be used on JWST
 - PRC vs IPI difference is larger than the accuracy of each individual instrument; however, the differences are comparable to the observed time-varying drift
 - A simultaneous PRC and IPI measurement of a fiducialized reference sphere would have significantly improved our understanding of the systematic errors
- Ongoing analysis:
 - Process PRC phase maps to correct the distortion, remove gravity, and remove alignment residuals (D. Chaney); then re-compare to IPI
 - ◆ Determine how closely the PRC-IPI residual error matches pure alignment errors
 - Demonstrate prescription retrieval techniques to develop starting phase map