ExoPlanet Exploration Program

Diamond turned high precision PIAA optics and four mirror PIAA system for high contrast imaging of exo-planets

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Outline

- Design of 2 mirror PIAA system with low sag mirrors for diamond turning at low cost
- Manufacture of Al, Cu and Ni/Invar 30 and 35mm dia mirrors on 2" blanks
- Profile and wavefront measurements of manufactured mirrors
- Analysis of manufacturing errors
- Initial results of coronagraph tests at NASA Ames Lab
- Four mirror PIAA system design with 30mm dia mirrors
- Manufactured Cu sets, pending Ni/Superinvar sets
- Wavefront measurements and error analysis
- Model predictions of 4 mirror system performance

Two Mirror PIAA system

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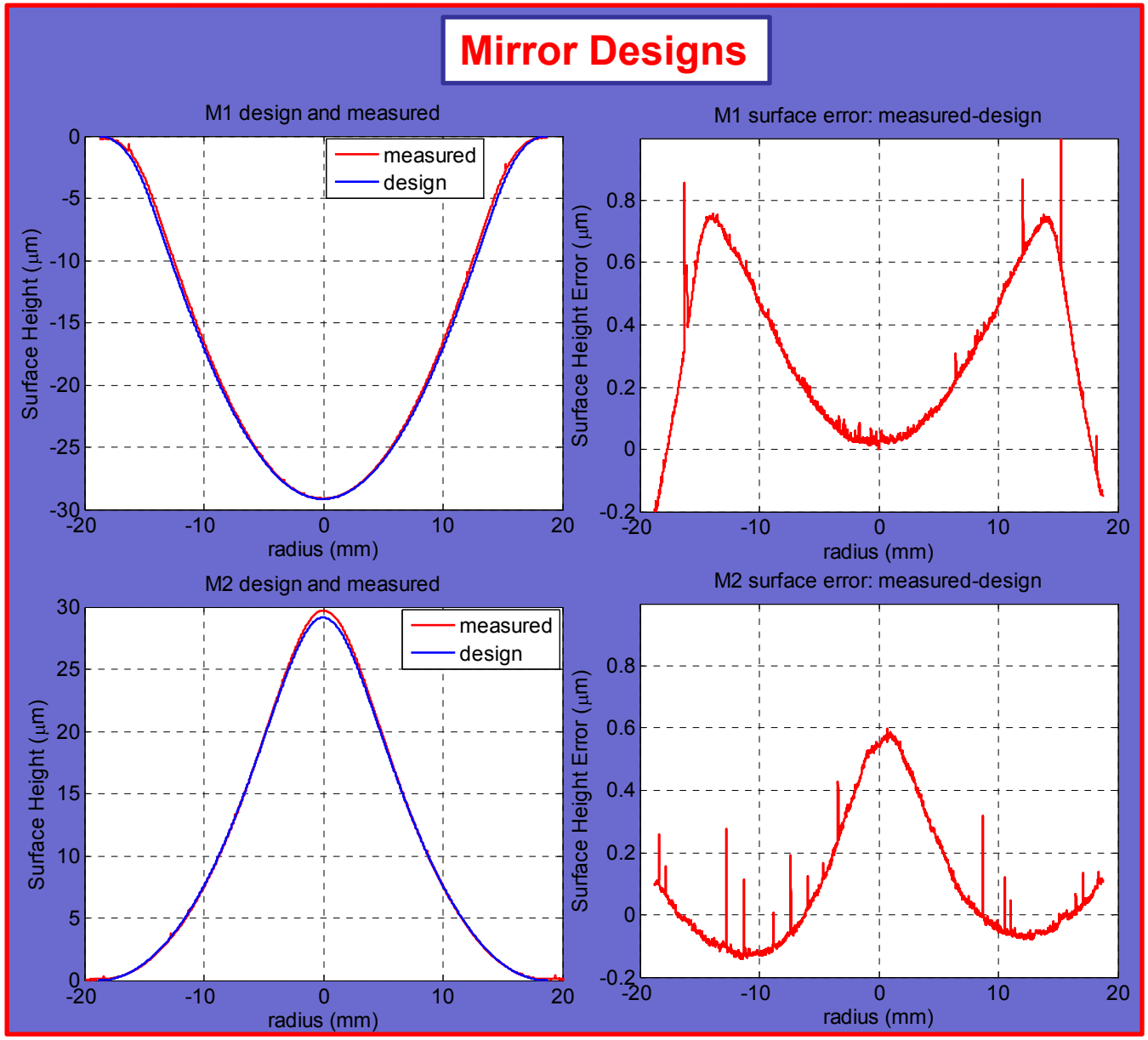
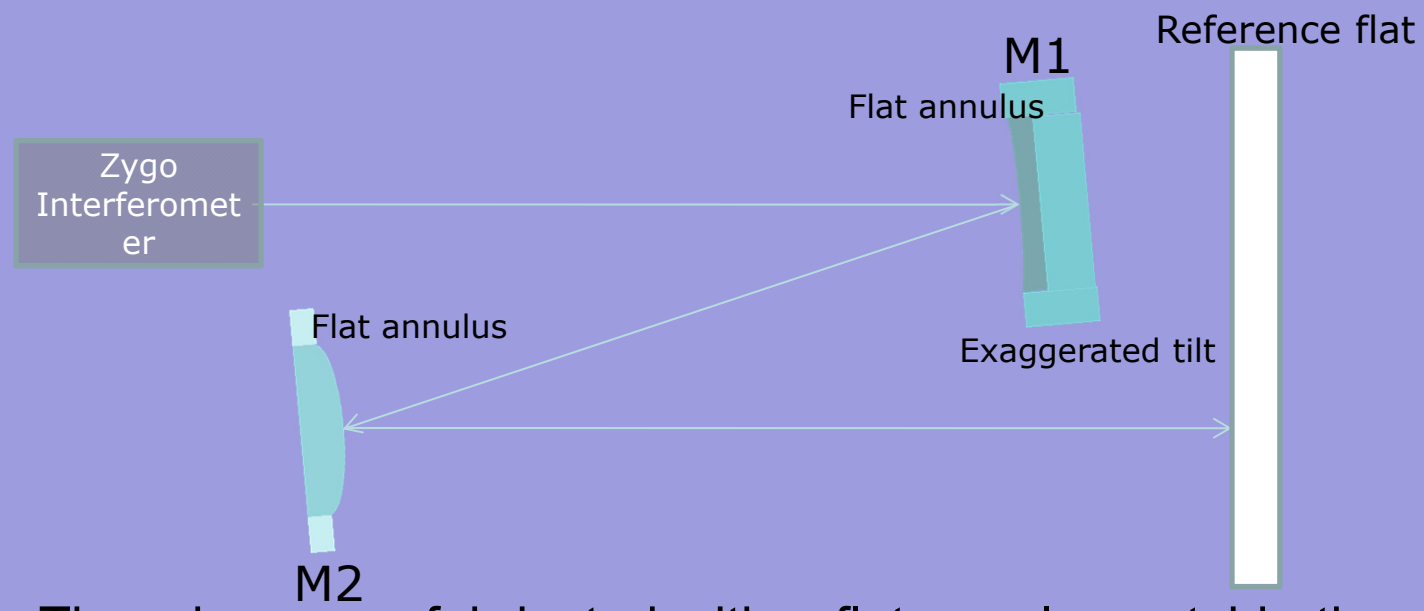


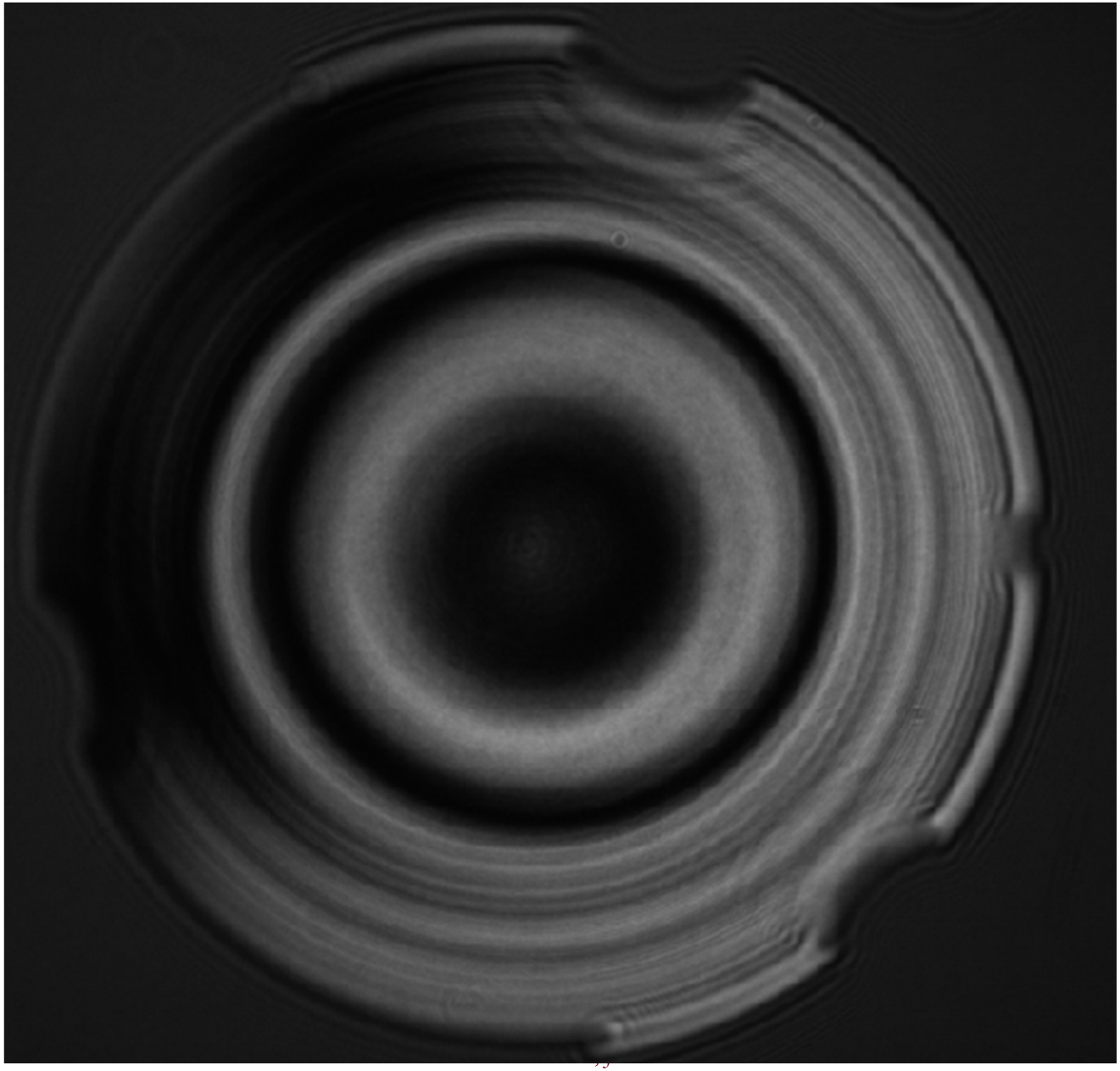
Two Mirror PIAA system



The mirrors are fabricated with a flat annulus outside the PIAA region. These are used to co-align the mirrors. First, a reference flat is aligned to the Zygo to fluff out the interference fringes. Then M1 and M2 are inserted, partially blocking the beam. M2 is tilted until the fringes in the annular region are fluffed out. The mirrors are then parallel to one another. Then M2 is translated to find the best position. This approach decouples tip/tilt from translation. The mirrors are circularly symmetric so there is no need to rotate about the central axis.

Two Mirror PIAA system

Double pass interferogram of PIAA pair



Two Mirror PIAA system

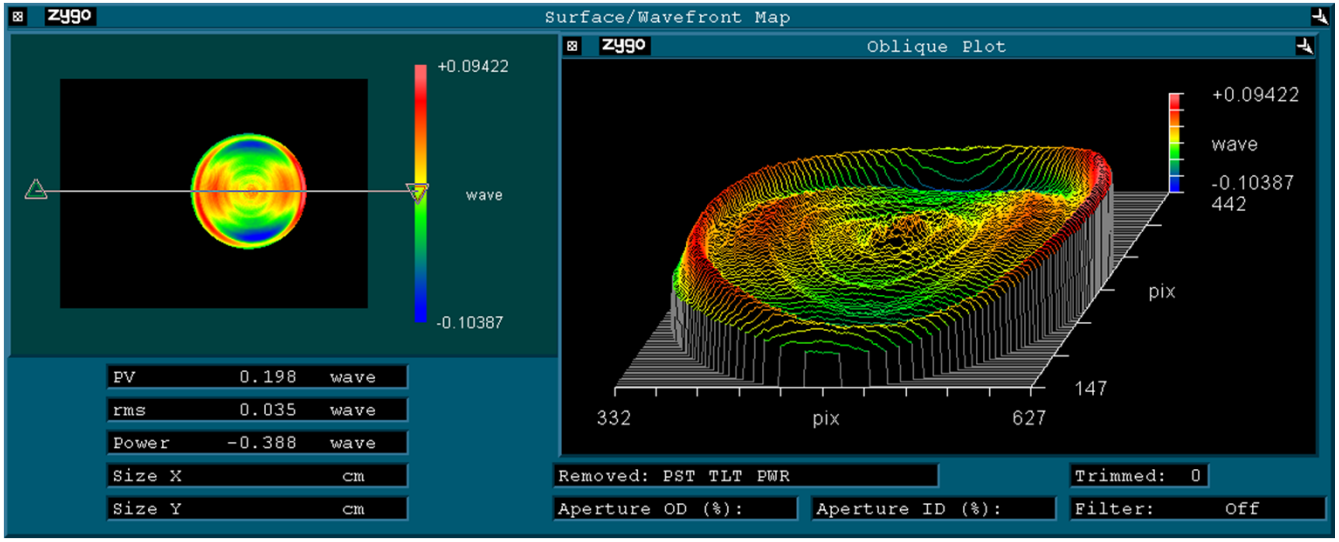
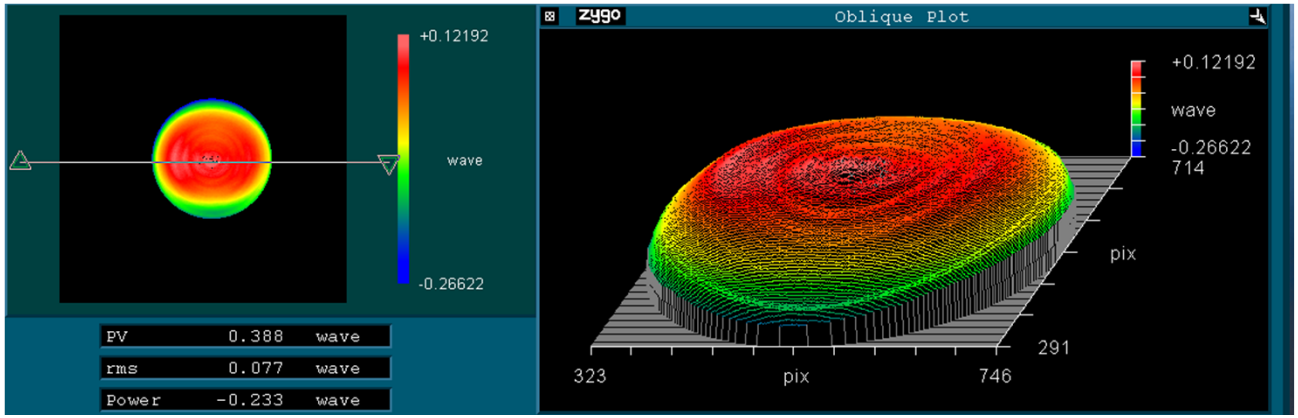


Figure 1. Zygo wavefront map of 30mm footprint Ni/SuperInvar PIAA mirror pair - Jan 10, 2011 in the newly set up lab with precision mounts and controls in 306-131; a factor of 2 improvement over the results from May 2010, see figure 2 below.



Two Mirror PIAA system

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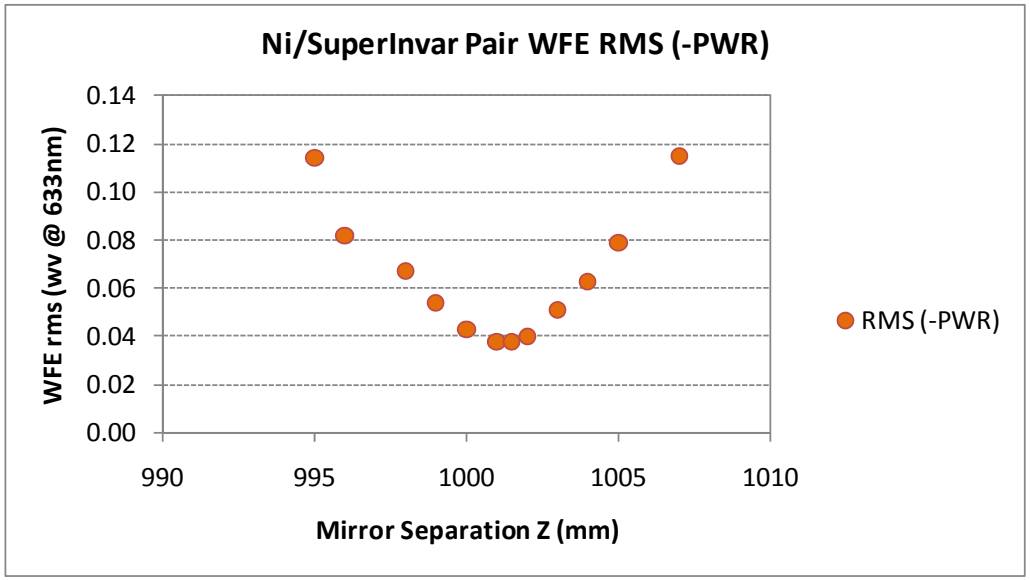
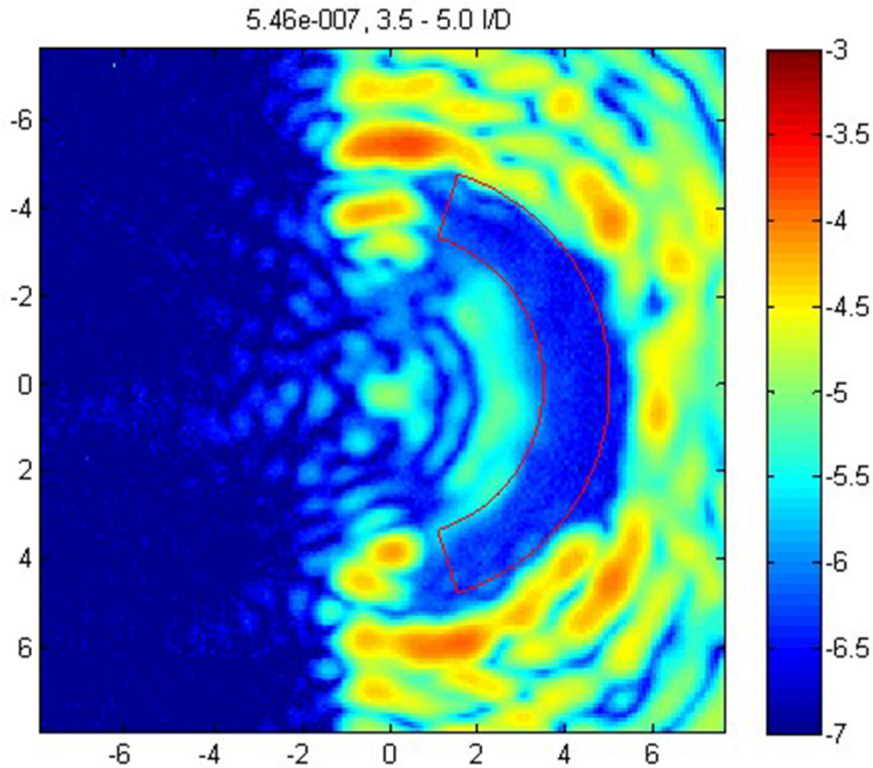


Two Mirror PIAA system

Ames Test Bed preliminary result



Belikov, et al., 2011, *Laboratory Demonstration of High Contrast Imaging at sub-2 λ/D Inner Working Angles, in* "Exploring Strange New Worlds: From Giant Planets to Super Earths", Flagstaff, AZ May 1-6, 2011

Four Mirror PIAA system

Four Mirror PIAA system

Four mirror system provides higher throughput (>80%) without increasing manufacturing complexity

The two-mirror system uses a post-apodizer to do the final beam shaping.

The second set of mirrors perform the same function with no loss of throughput.

The two pairs must be designed together, so the nominal input to the second set is the remapped field from the first set.

Initial set was diamond-turned from 4 2” copper substrates, and the surface was measured with a profilometer.

Four Mirror PIAA system

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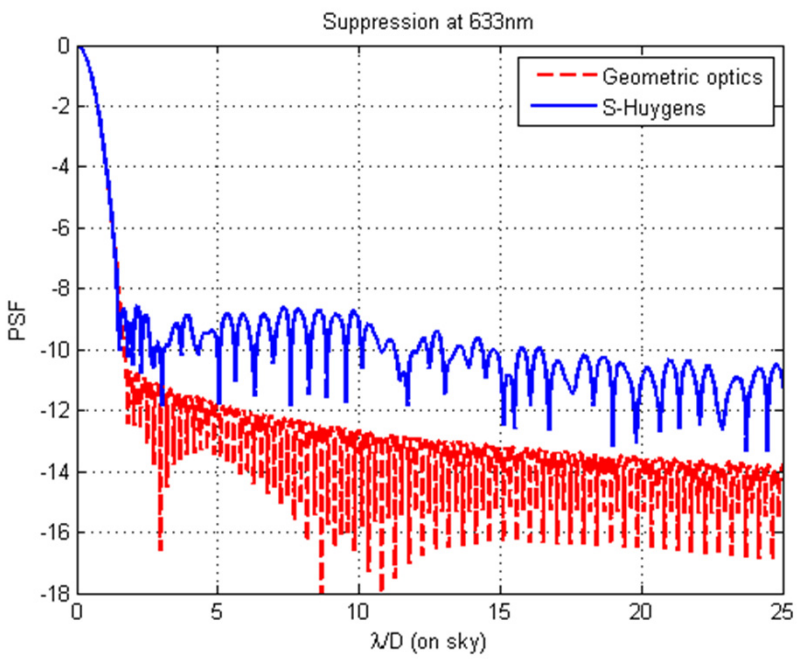
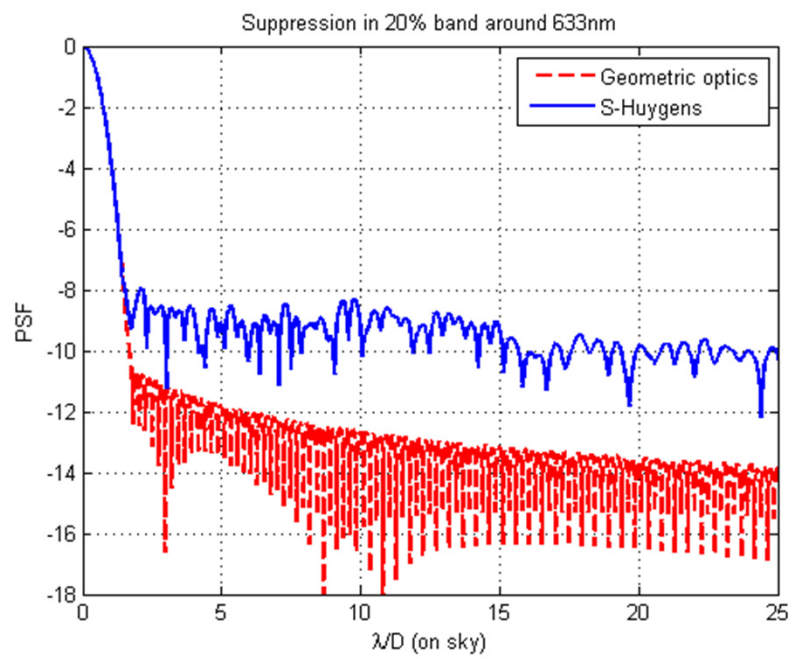
A comparison of the theoretical performance of the 4-mirror system based on geometric optics, and the performance with diffraction effects included.



Avg. contrast 1.5 λ/D-10λ/D: 7.28e-10



Avg. contrast 1.5 λ/D-10λ/D: 1.5e-9

Employing a DM, one can achieve better contrast

Profiles and errors

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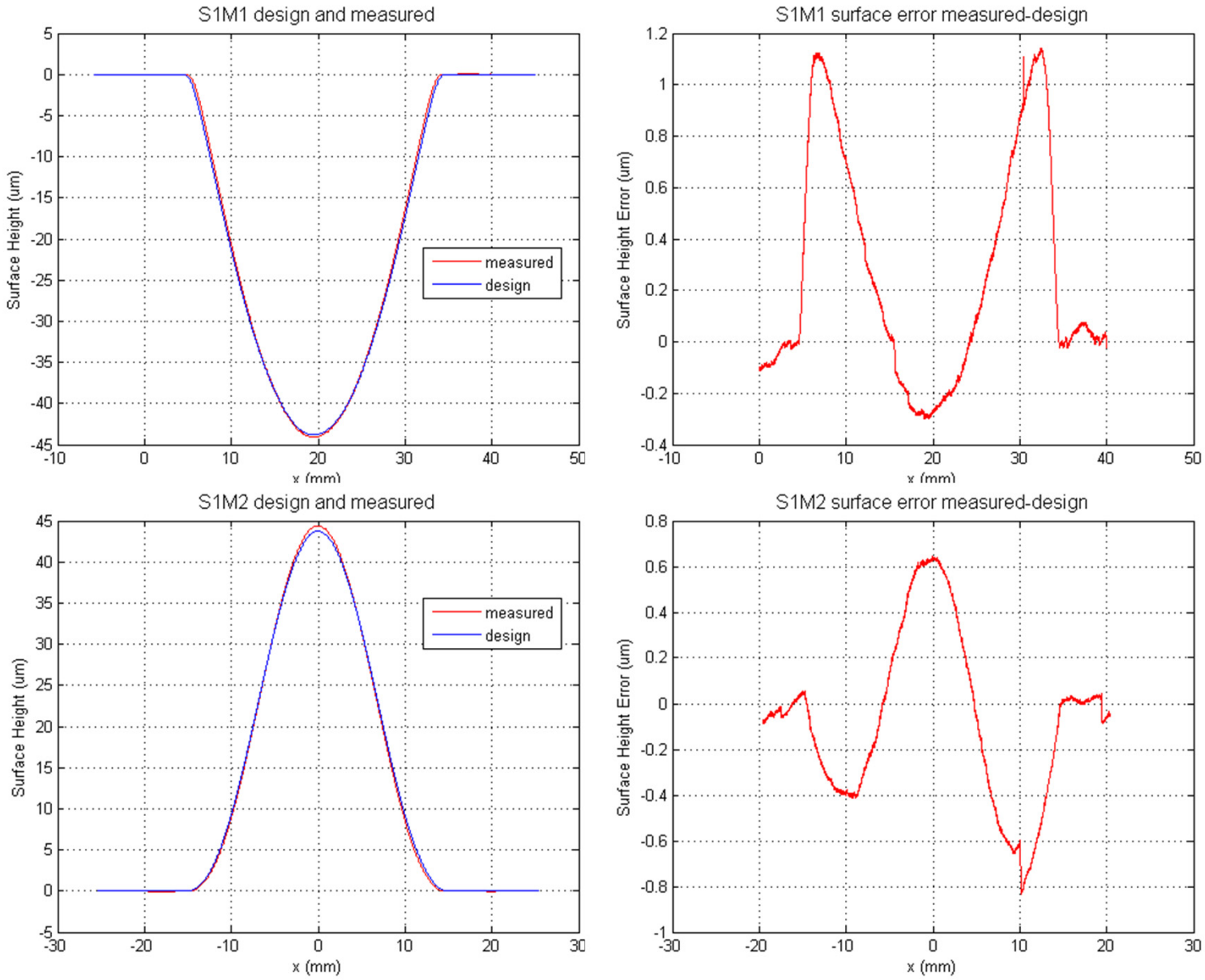
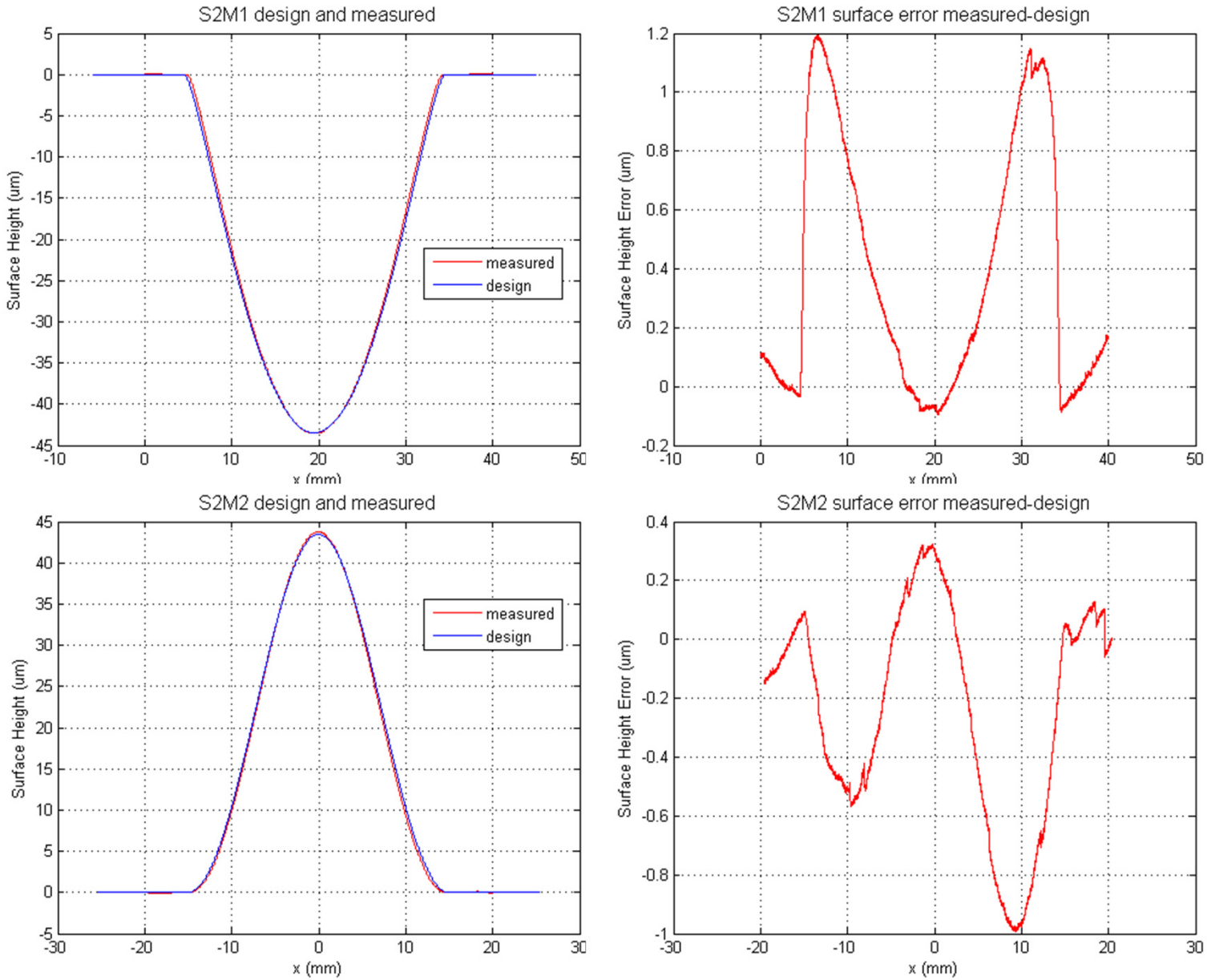
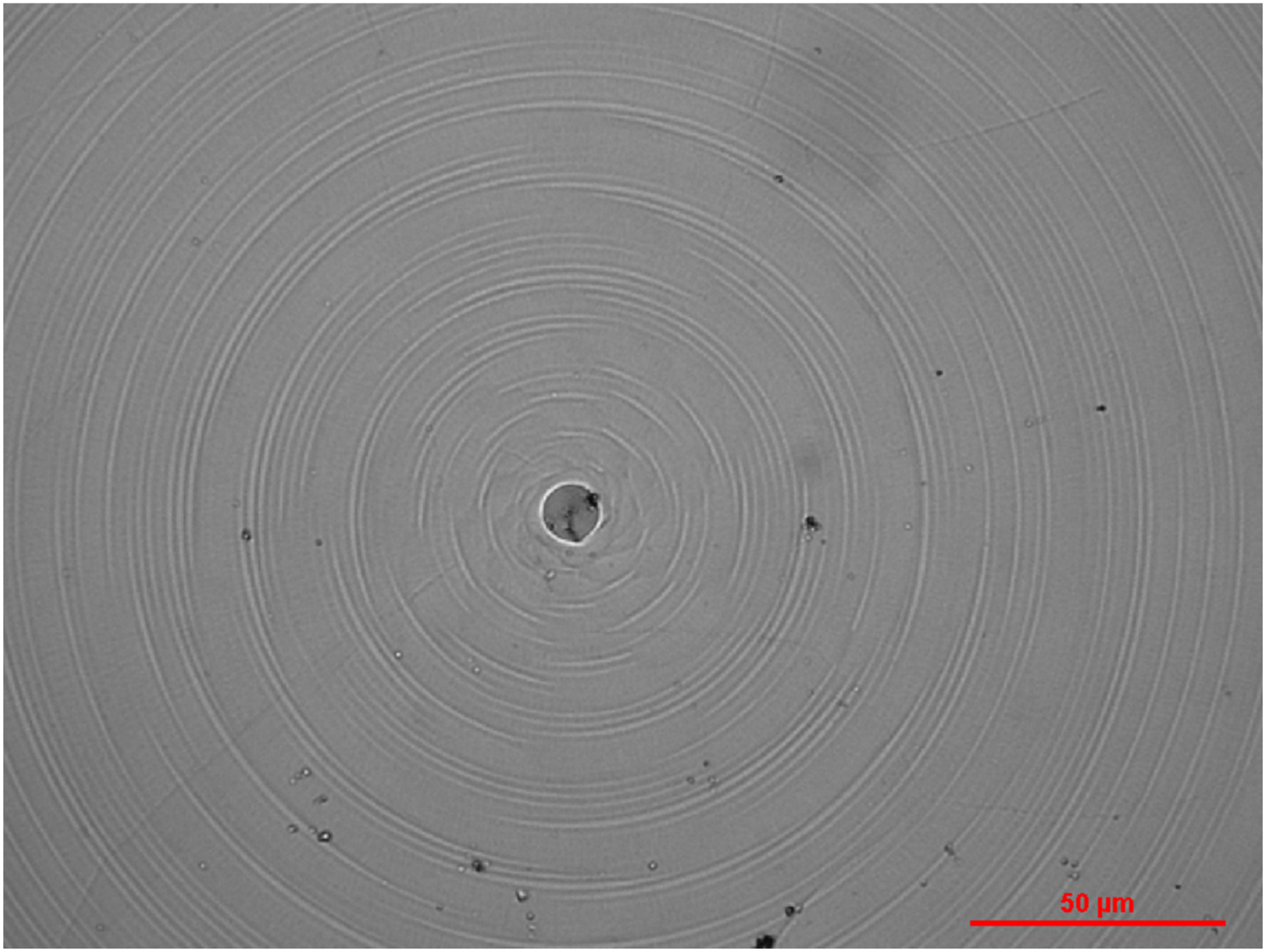


Profiles and errors



Inner region of Cu mirror M1



Four Mirror PIAA system

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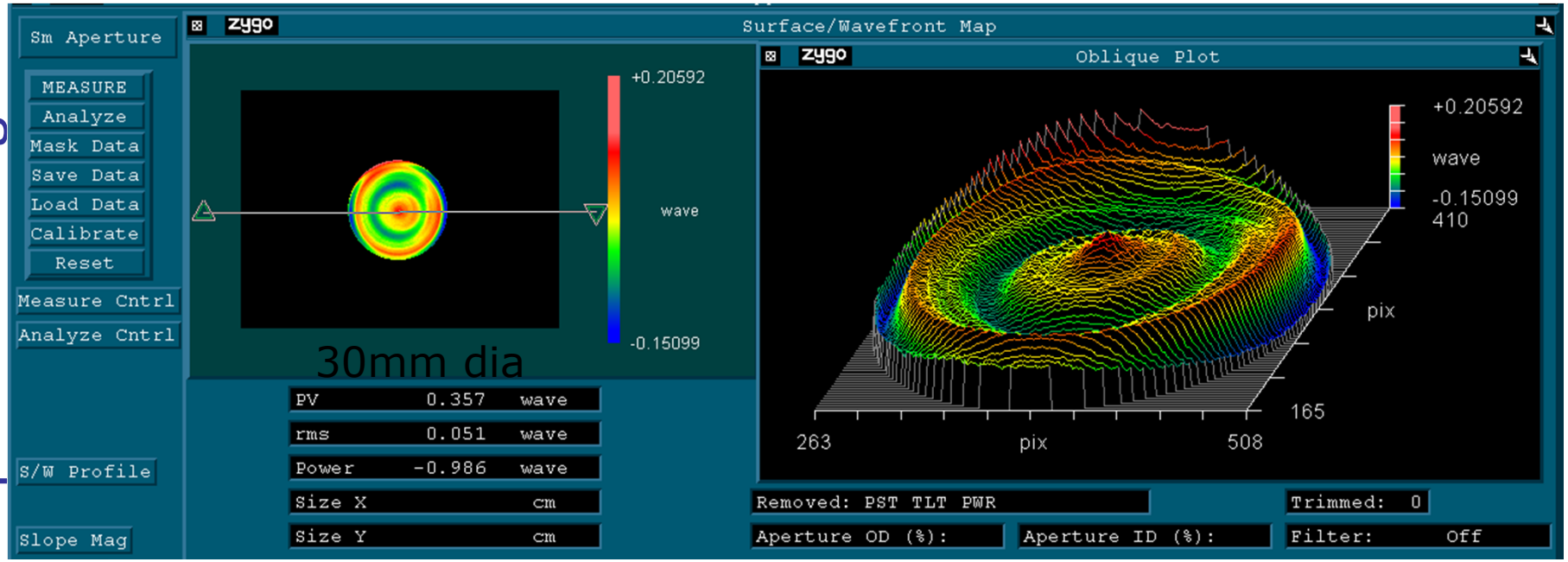
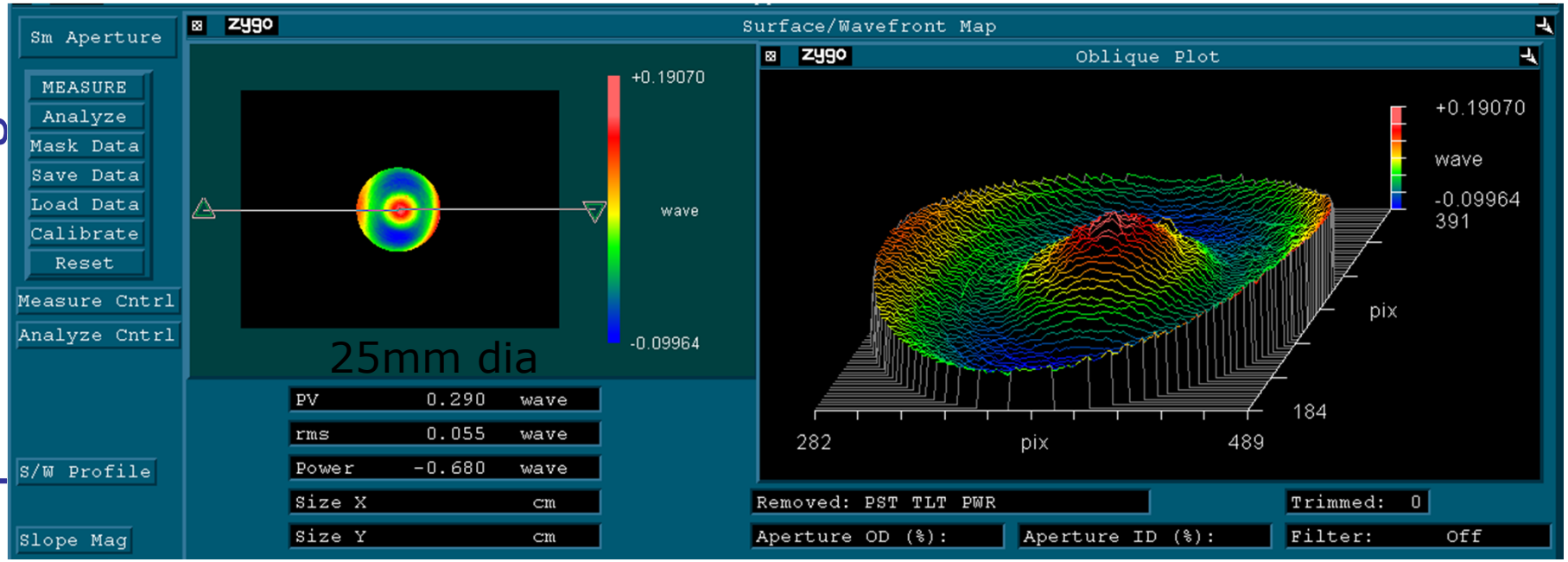
CuS1 pair aligned with 3.2deg AOI on M1 and near optimum M1-M2 dist



Four Mirror PIAA system

ExoPlanet Exploration Program

CuS2 pair aligned with 3.2deg AOI on M1 and near optimum M1-M2 dist



Four Mirror PIAA system

Next steps:

- Iterate on mirror shape to eliminate 2λ P-V shape manufacturing error

- Measure double-pass wavefront from full 4-mirror setup and measure sensitivities to alignment at JPL

- Test in Ames testbed with DMs and pre-apodizer

Summary & Conclusions

	Two Mirror PIAA system	Four Mirror PIAA system
Mirrors cost Total	<5K	<10K
Throughput	~ 50%	>80%
BW	20%	20%
Apodizers	pre and post required	Only pre-apodizer
BB Contrast	~ 1e-10 at 2λ/D	~ 1.5e-9 at 1.5λ/D (design dependent)
Measured contrast	5.5e-7 at 633nm (limited by manufacturing errors and system instabilities)	TBD

Acknowledgements

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