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PVr – a robust amplitude parameter for surface and wavefront specification

Chris J. Evans

1/20/2008

cevans@zygo.com

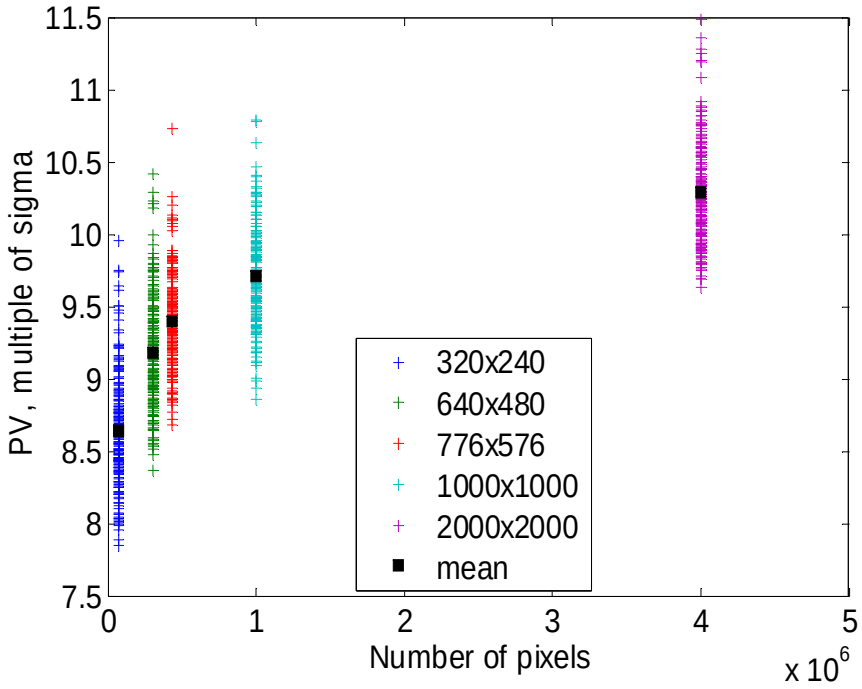
Outline

- Introduction
- PVr definition
- Examples
- Suggested implementation

Why do we need another parameter?

- Modern optics specification:
  - rms_i, PSD, slope
- Historical (entrenched)
  - λ/N (ie PV_i)
  - Loosely related to imaging for conventional fabrication methods and heavily filtered data
- Uncertainty in PV tough to evaluate

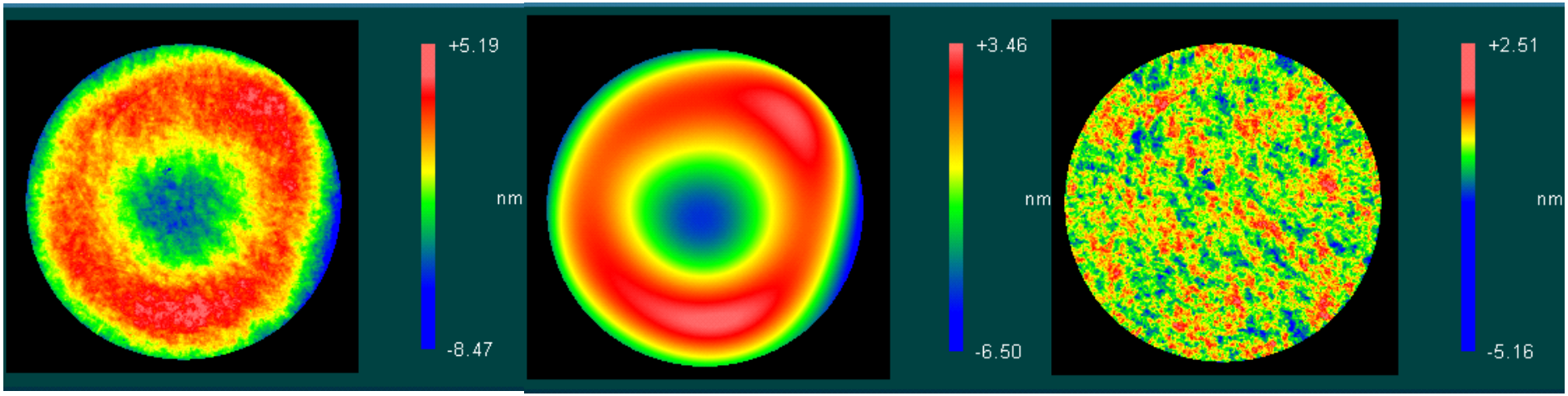
PV is biased by noise*



* PV_{bias} = f(skew, kurtosis) , Evans, Annals of CIRP, submitted

PVr – a robust PV-like parameter

- For circular apertures:
  - $PVr = PV_{36Zernikes*} + 3 \times \sigma_{36\ ZernikeResid}$



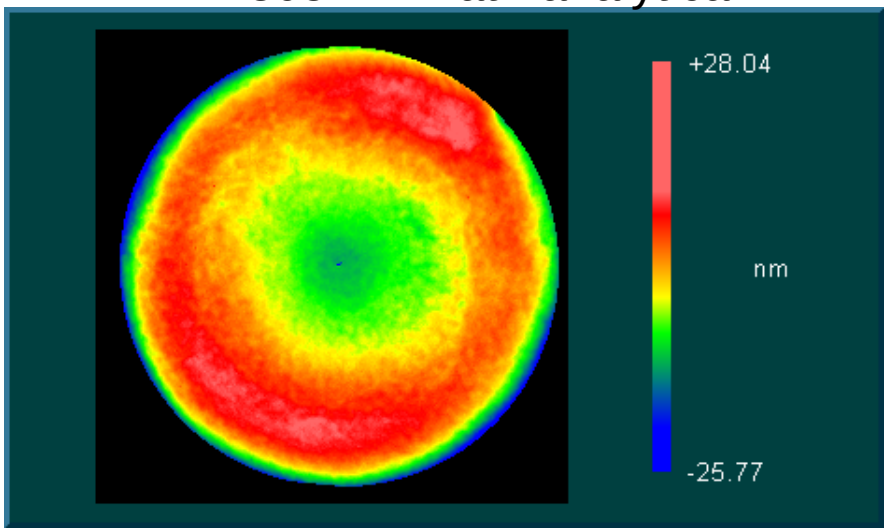
PV = 13.7 nm, rms = 2.1 nm PV = 10.0 nm, rms = 2.1 nm PV = 7.7 nm, rms = 0.5 nm

  - PVr = 10.0 + 3 x 0.5 = 11.5 nm

* Terms to r^{12} and 5θ

What is meant by robust?

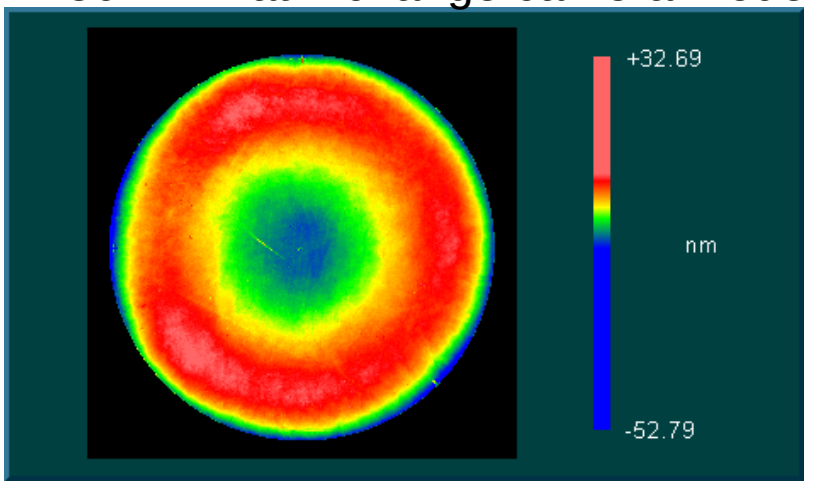
305 mm flat - analytical



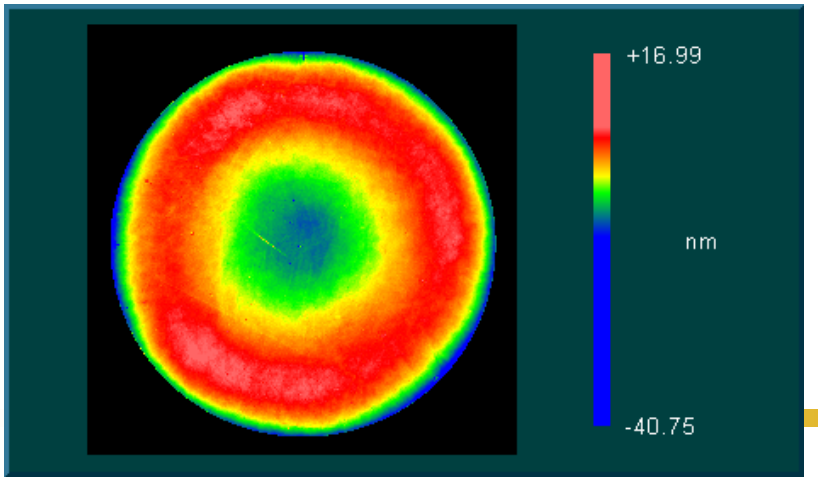
Detector resolution	PV, nm	PVr, nm
1024 x 1024	53.81	39.46
512 x 512	38.27	39.41
256 x 256	36.88	39.33
128 x 128	33.90	39.19

* Pixel averaging

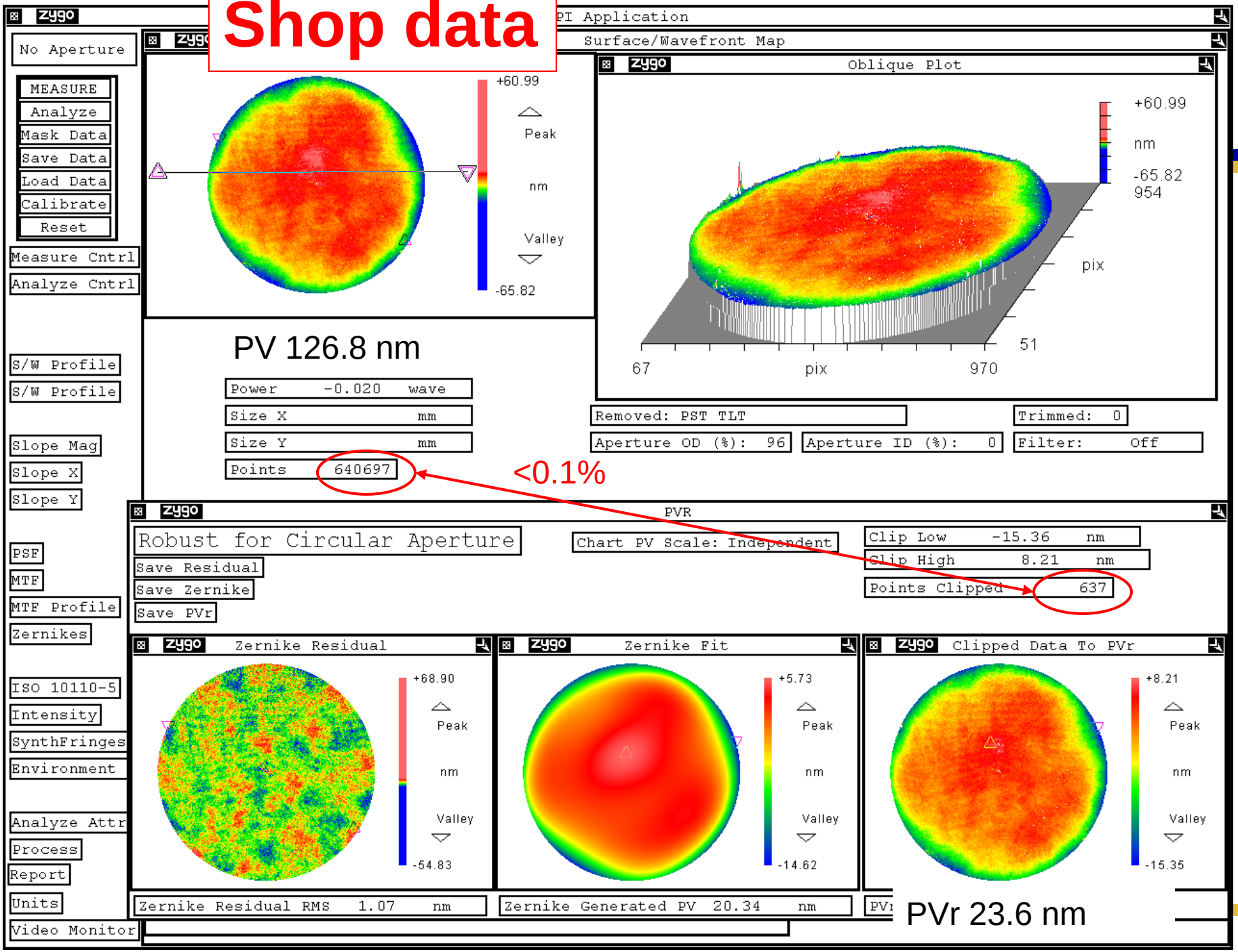
150 mm flat – change camera mode



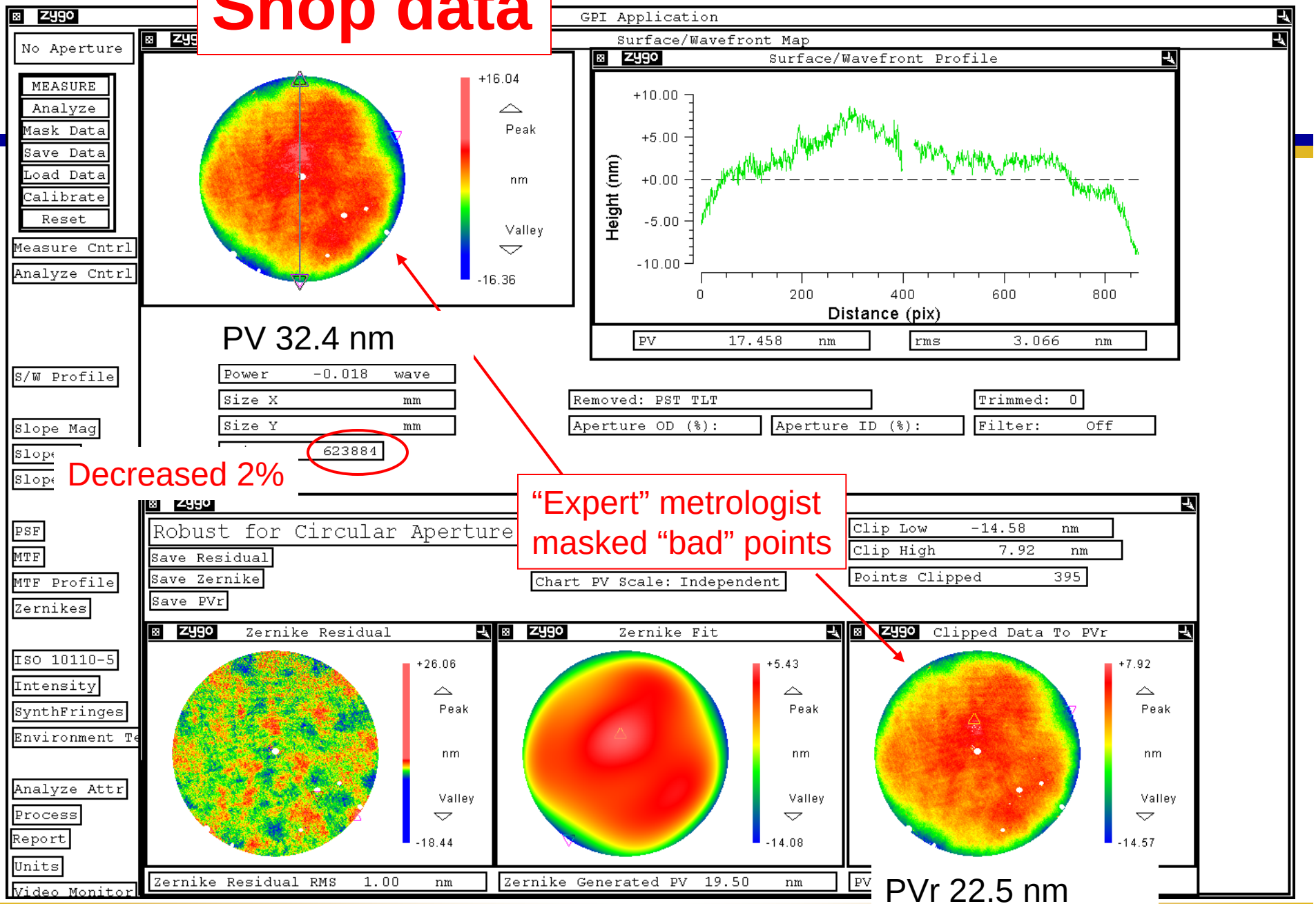
Above: 1k x 1k; PV= 85.5 nm, PVr=22.4 nm
Below: 500 x 500;PV=57.7 nm, PVr =21.6 nm



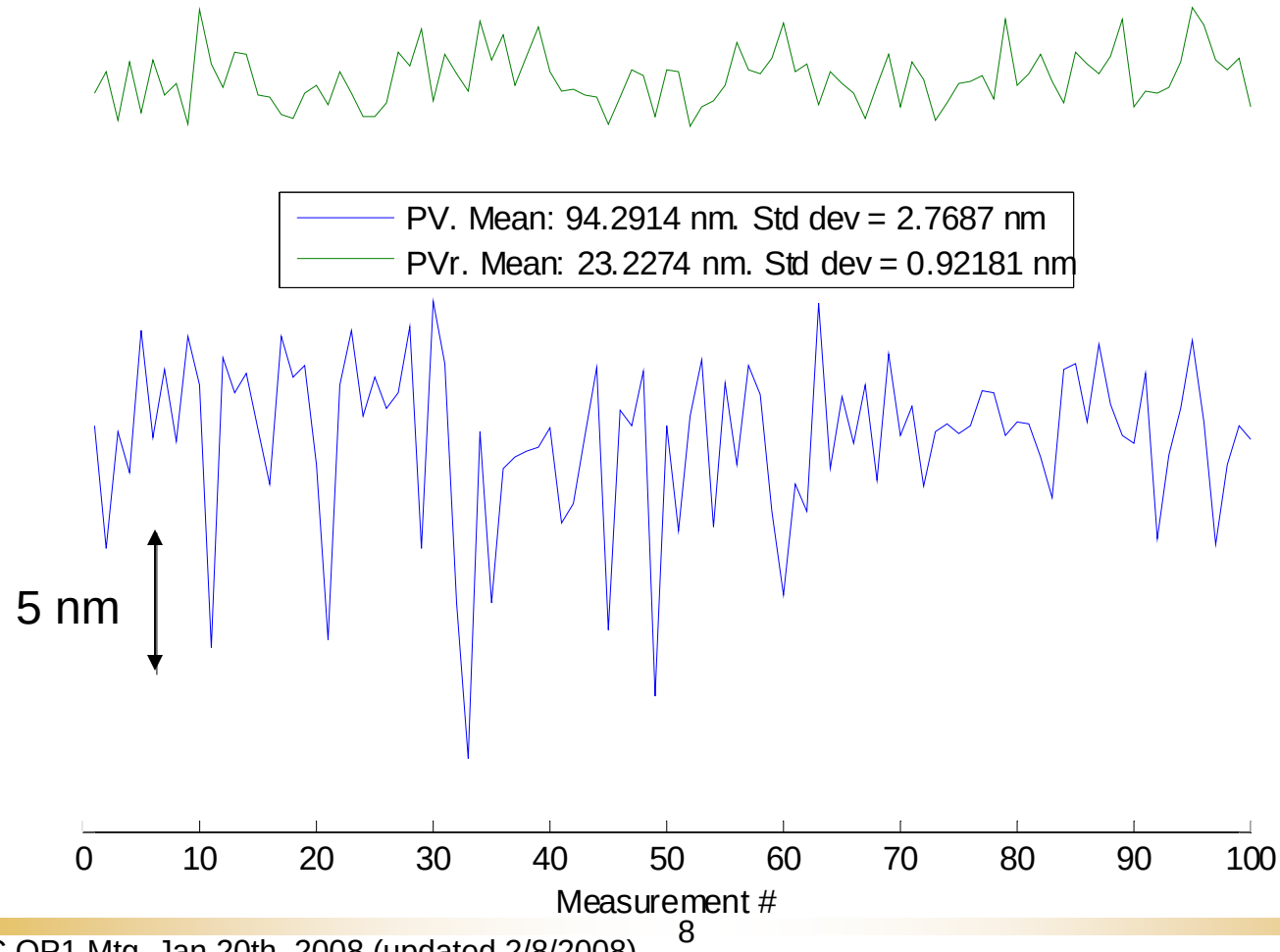
Shop data


PI Application
Surface/Wavefront Map
No Aperture
MEASURE
Analyze
Mask Data
Save Data
Load Data
Calibrate
Reset
Measure Cntrl
Analyze Cntrl
S/W Profile
S/W Profile
Slope Mag
Slope X
Slope Y
PSF
MTF
MTF Profile
Zernikes
ISO 10110-5
Intensity
SynthFringes
Environment
Analyze Attr
Process
Report
Units
Video Monitor
+60.99
Peak
nm
Valley
-65.82
Oblique Plot
+60.99
nm
-65.82
954
pix
67
pix
970
51
PV 126.8 nm
Power -0.020 wave
Size X mm
Size Y mm
Points 640697
Removed: PST TLT
Trimmed: 0
Aperture OD (%): 96
Aperture ID (%): 0
Filter: Off
<0.1%
PVR
Robust for Circular Aperture
Save Residual
Save Zernike
Save PVr
Chart PV Scale: Independent
Clip Low -15.36 nm
Clip High 8.21 nm
Points Clipped 637
Zernike Residual
+68.90
Peak
nm
Valley
-54.83
Zernike Fit
+5.73
Peak
nm
Valley
-14.62
Clipped Data To PVr
+8.21
Peak
nm
Valley
-15.35
Zernike Residual RMS 1.07 nm
Zernike Generated PV 20.34 nm
PVr 23.6 nm

Shop data

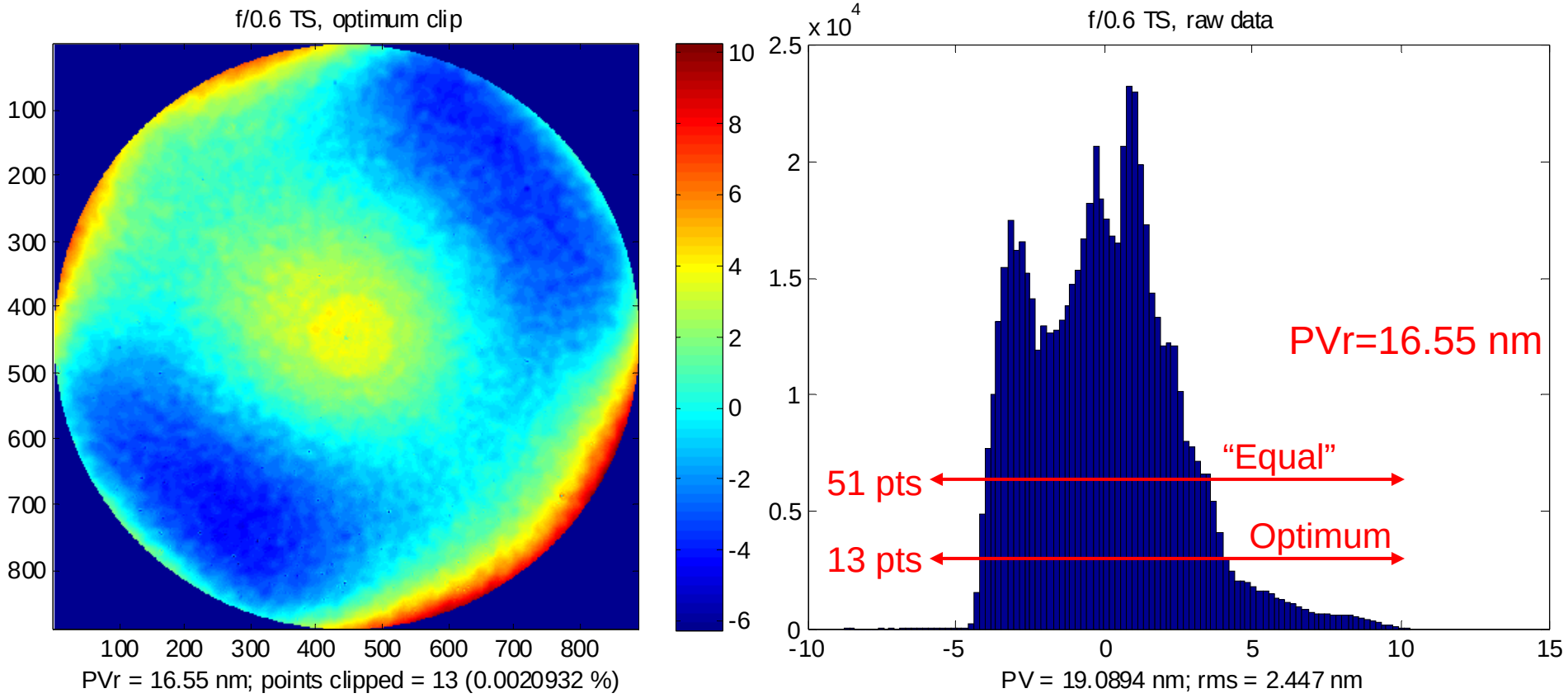

GPI Application
Surface/Wavefront Map
Surface/Wavefront Profile
No Aperture
MEASURE
Analyze
Mask Data
Save Data
Load Data
Calibrate
Reset
Measure Cntrl
Analyze Cntrl
+16.04
Peak
nm
Valley
-16.36
+10.00
+5.00
+0.00
-5.00
-10.00
Height (nm)
0
200
400
600
800
Distance (pix)
PV 17.458 nm
rms 3.066 nm
PV 32.4 nm
Power -0.018 wave
Size X mm
Size Y mm
623884
Decreased 2%
S/W Profile
Slope Mag
Removed: PST TLT
Trimmed: 0
Aperture OD (%):
Aperture ID (%):
Filter: Off
"Expert" metrologist masked "bad" points
Robust for Circular Aperture
Save Residual
Save Zernike
Save PVr
Chart PV Scale: Independent
Clip Low -14.58 nm
Clip High 7.92 nm
Points Clipped 395
PSF
MTF
MTF Profile
Zernikes
ISO 10110-5
Intensity
SynthFringes
Environment Te
Analyze Attr
Process
Report
Units
Video Monitor
Zernike Residual
+26.06
Peak
nm
Valley
-18.44
Zernike Fit
+5.43
Peak
nm
Valley
-14.08
Clipped Data To PVr
+7.92
Peak
nm
Valley
-14.57
Zernike Residual RMS 1.00 nm
Zernike Generated PV 19.50 nm
PVr 22.5 nm

Raw data variation

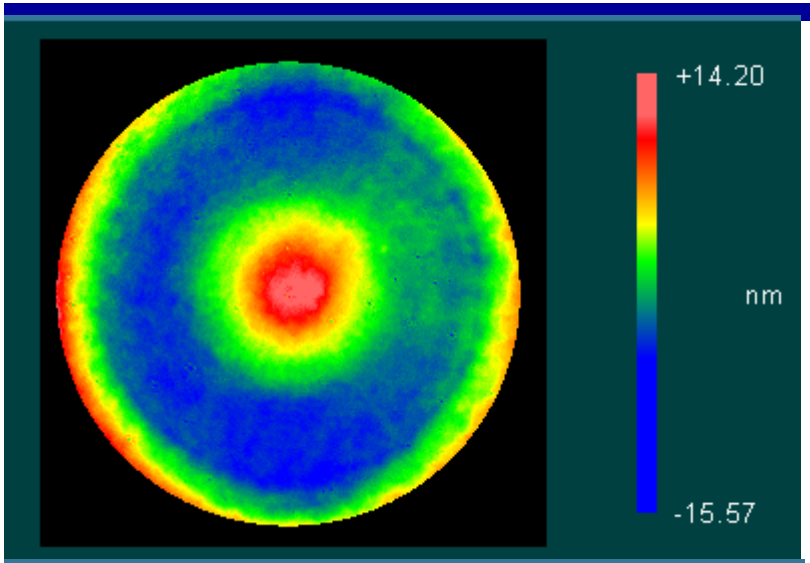


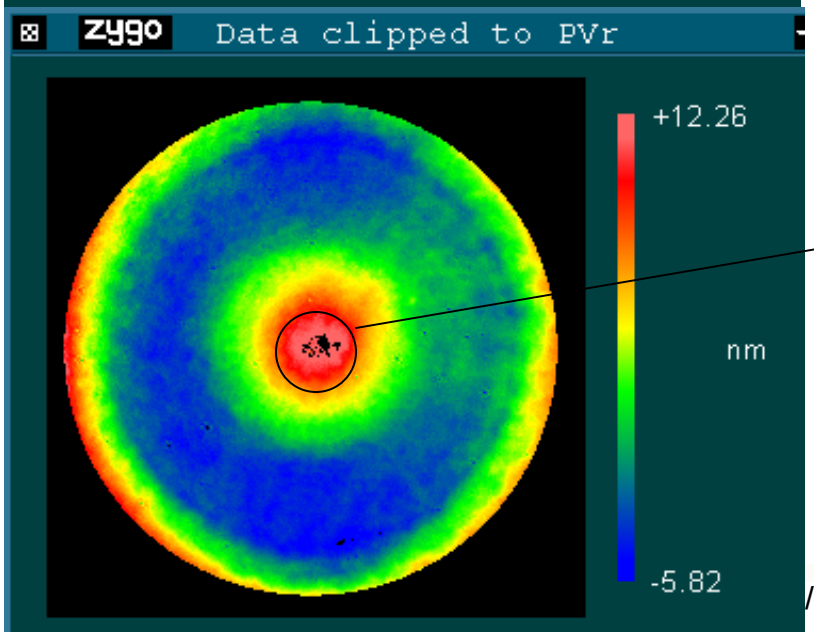
“Clipping”

- PVr<PV – how many points not included in characterization of the surface/wavefront?

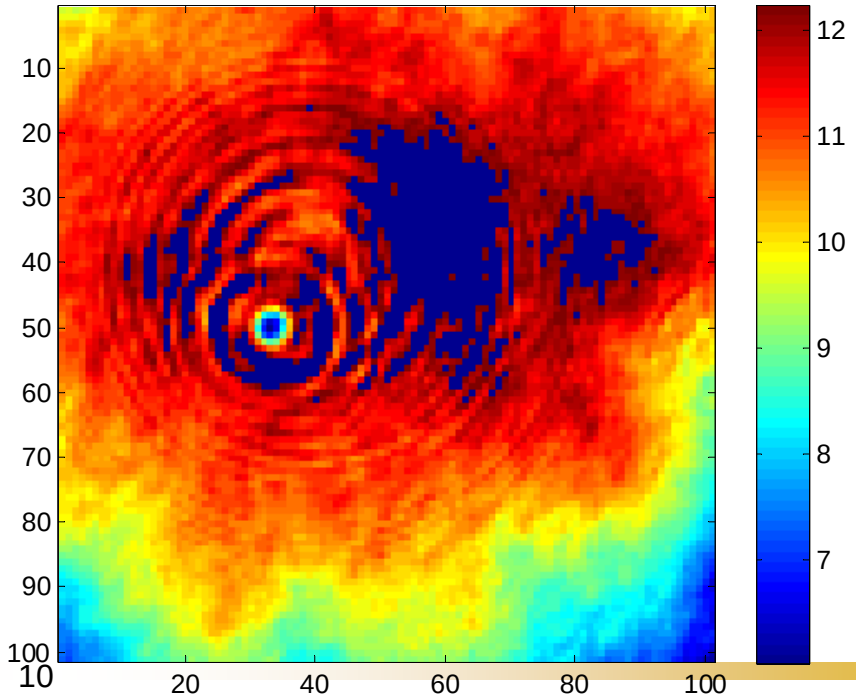


Clipping (continued)





PV = 29.8 nm, PVr = 18.1 nm



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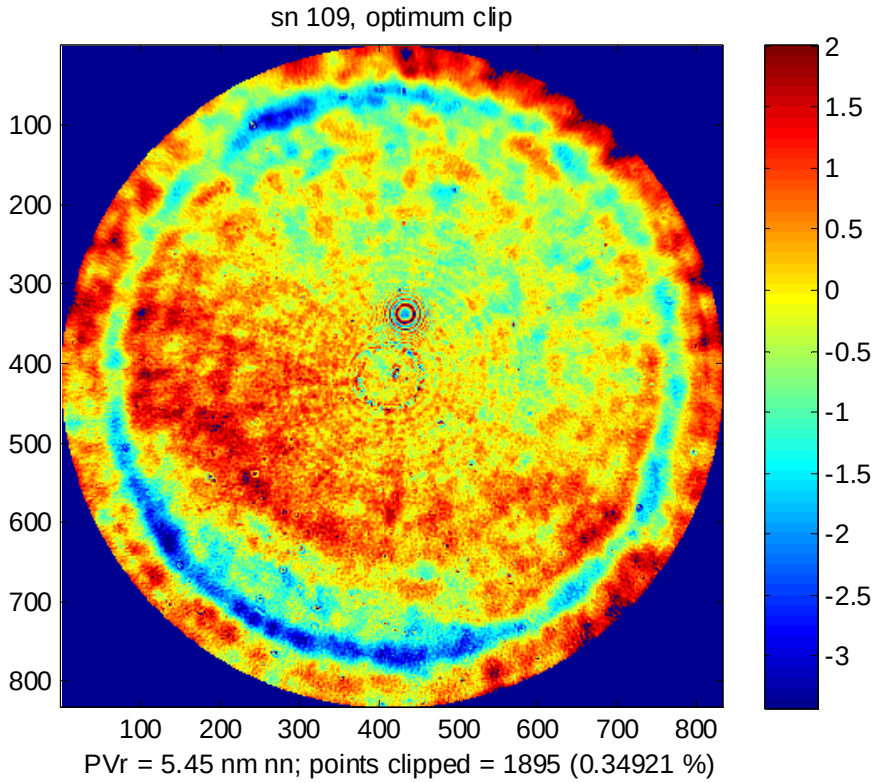
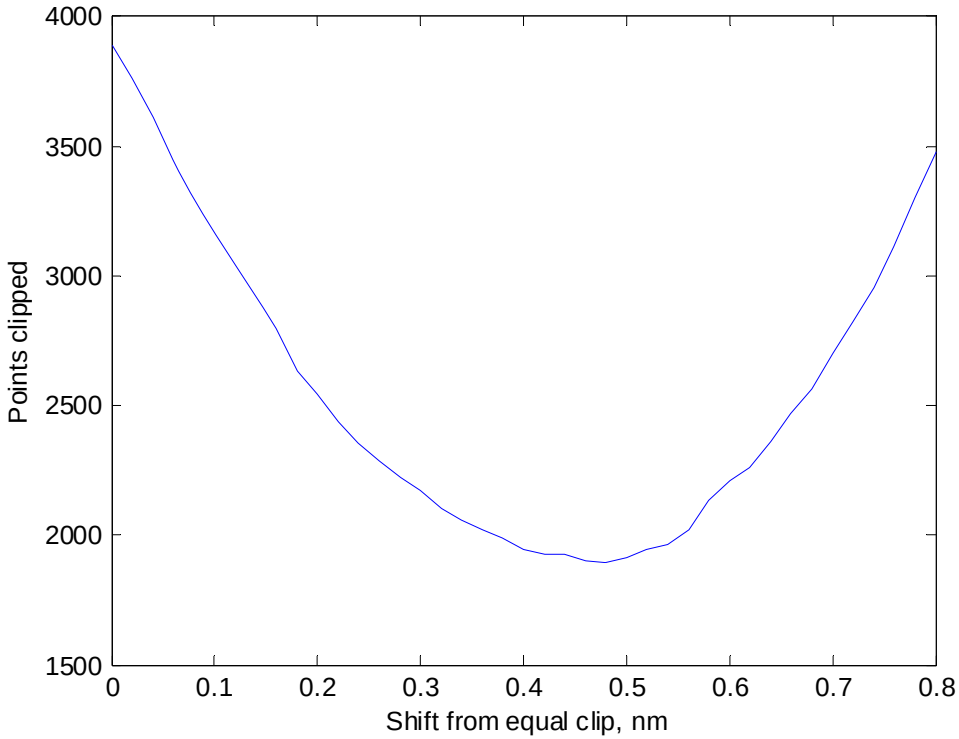
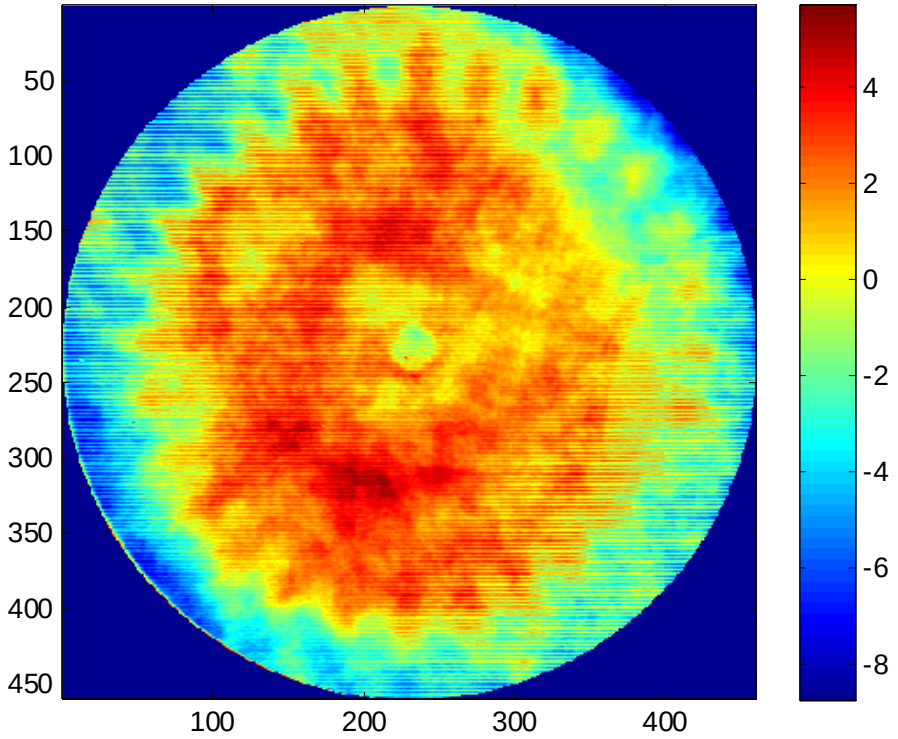
Clipping (continued)





PVr > PV?

- Checks for obvious errors (non-circular aperture, pathological data sets).



Interlace noise (up to 5 nm PV) in the presence of turbulence gave zero noise on “peak”.

PVr examples

Experimental data							
#	Part	PV (nm)	rms (nm)	PV:rms ratio	PVr (nm)	rms (nm)	PVr:rms ratio
1	f/0.75, 65 mm aperture	30.1	1.03	29	8.5	1.03	8
2	f/45 cavity	68.2	10.01	7	63.1	10.01	6
3	Zerodur test sphere	25.9	1.99	13	13.6	1.99	7
4	800 mm aperture flat	162.9	20.68	8	147.9	20.68	7
5	300 mm calibration flat	147.9	11.42	13	51.5	11.42	5
6	305 mm TF	26.4	5.21	5	24.0	5.21	5
7	101.4 mm TF	13.7	1.85	7	10.6	1.85	6
8	300 mm long cavity	45.4	4.9	9	31.1	4.9	6
9	200 mm spherical cavity	23.8	2.64	9	16.1	2.64	6
10	Steep asphere	62.8	6.31	10	43.9	6.31	7

PVr < 6 $\sigma_{36\ ZernikeResid}$?

- Checks for “smooth surface” limit
  - For surface with $PV_{36Zernikes*} \sim 0$
  - If the residual has Gaussian height distribution, 6 $\sigma_{36\ ZernikeResid}$ represents 99.7% of height data.

PVr proposal

- For circular apertures:
  - $PVr = PV_{36Zernikes^*} + N \times \sigma_{36\ ZernikeResid}$
  - Default N=3
  - $6\sigma_{36\ ZernikeResid} < PVr < PV$
- Options (must be specified)
  - 1<N<6
  - Limit clip total area
  - Limit maximum contiguous clip area