

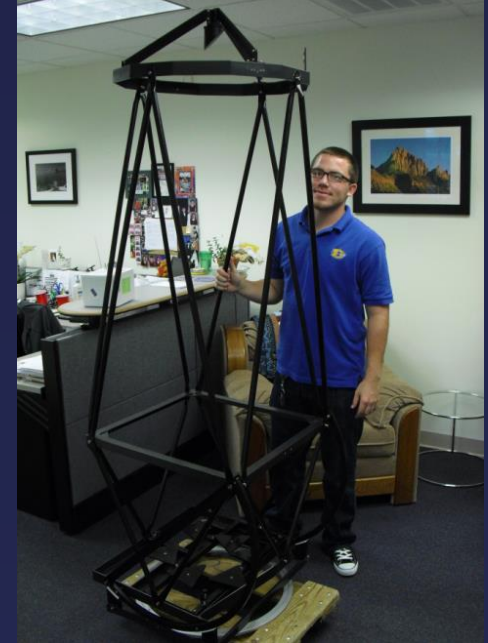
Optical Testing of Light Bucket Mirrors

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**Small Telescopes and Astronomical Research
(STAR III) Conference**

Lander University, Greenwood, South Carolina
June 6-7, 2014

Some Mirrors Tested

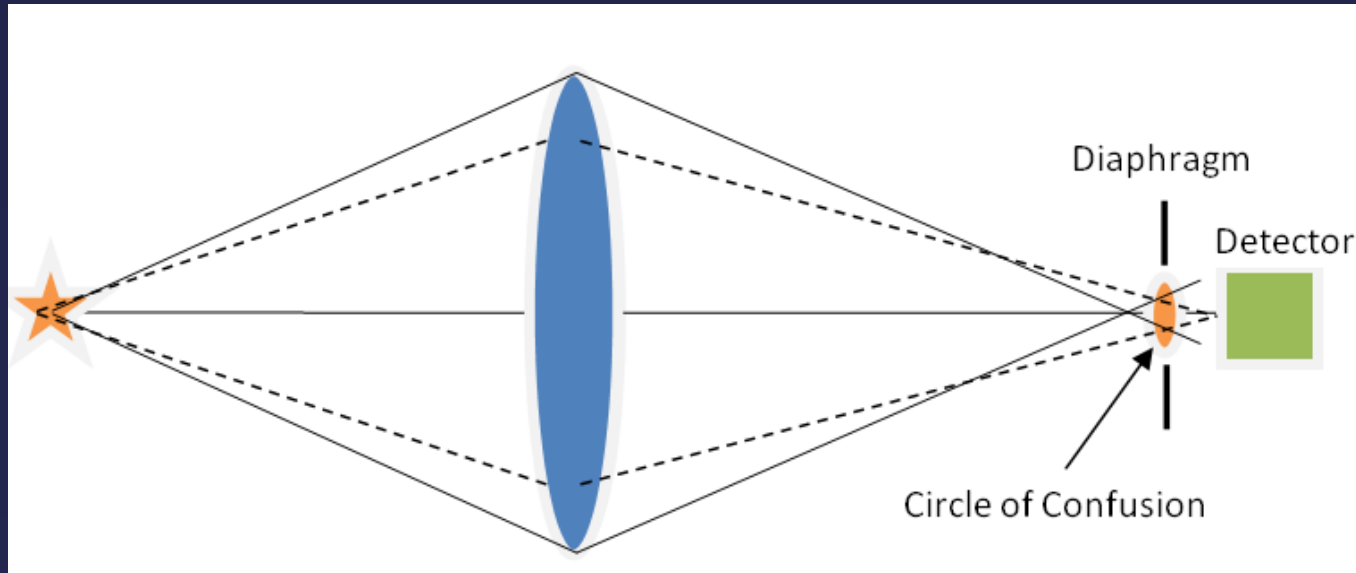


Tests & Measures

- Foucault, Ronchi, Interferometry, Artificial star PSF
- Physical parameters
 - Materials, Weight, Usable D, CTE, Focal Length and F/#
- Figure (conic)
- Aberrations present & magnitude: P-V, Strehl
- Smoothness
- Reflectivity



Circle of Confusion



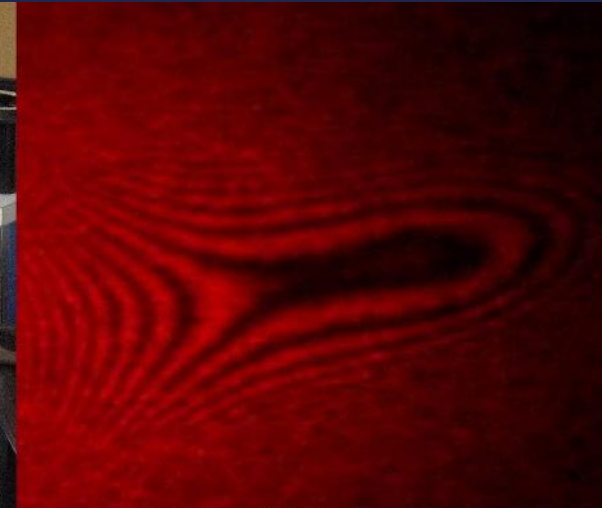
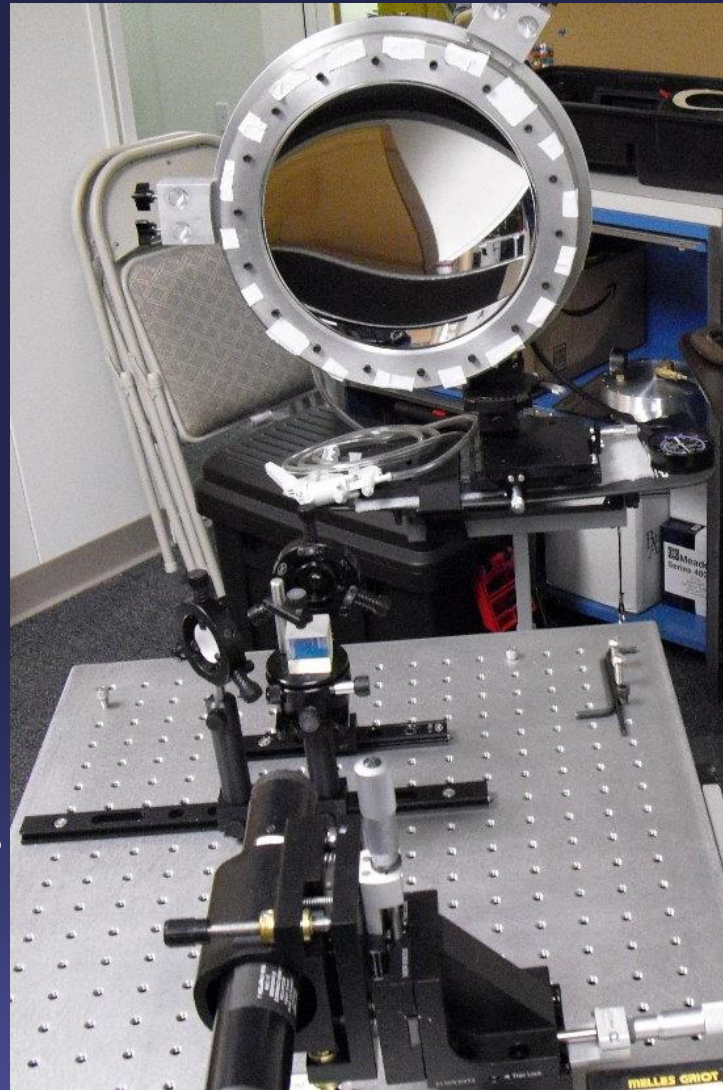
- Circle of Confusion = blur spot at focal plane
- Diaphragm = circular isolator before the detector



Vega – 12" pneumatic mirror, 1' dia.

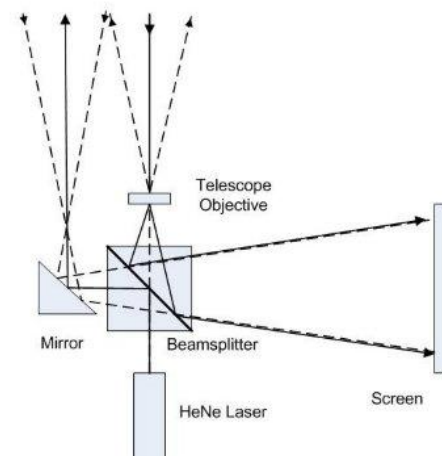
Aberration Characterization

- Zone-sampling with a Right-angle Bath Interferometer
- Analysis produces Zernike representation of wavefront , $W(\rho,\theta)$
- Stitching and statistical combination of sample zone results



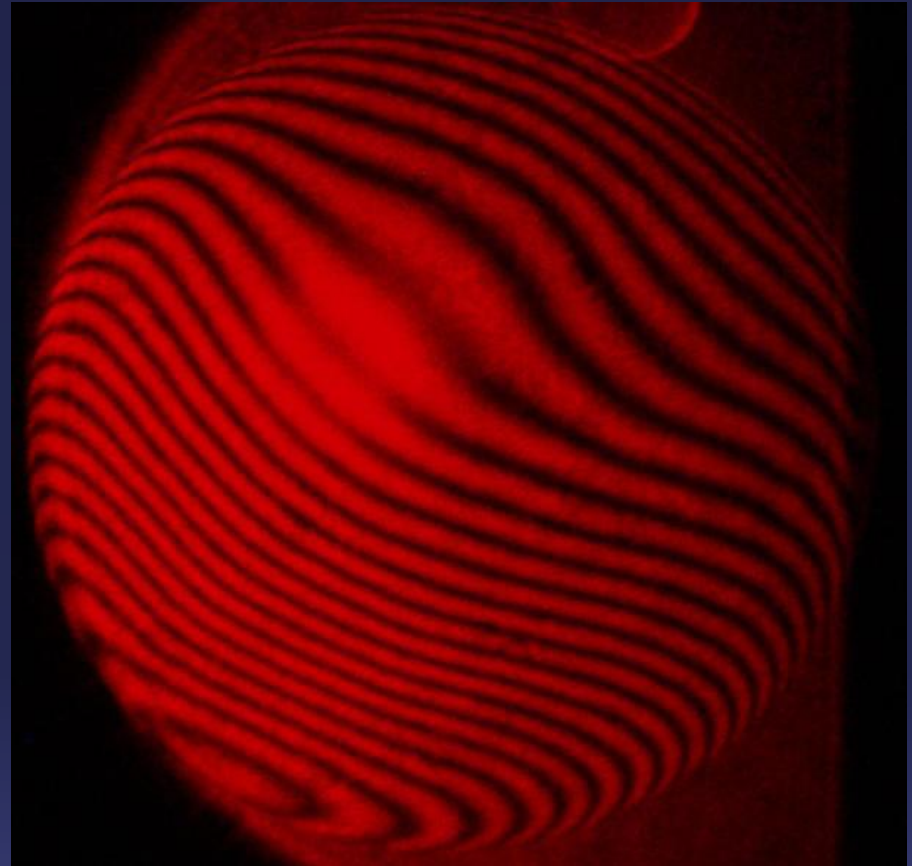
Right-Angle Bath Interferometer

TO MIRROR UNDER TEST



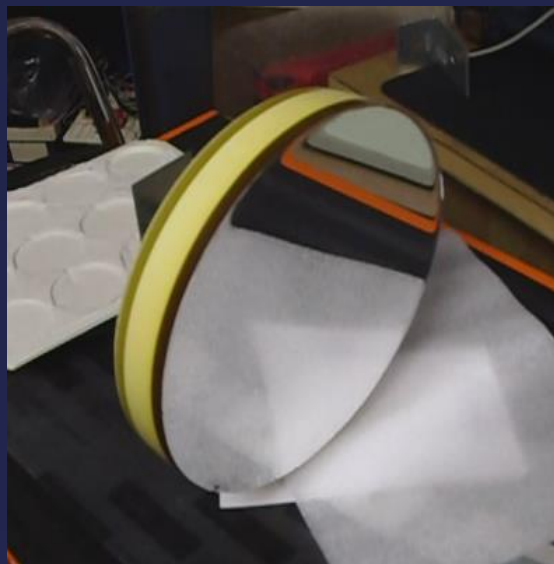
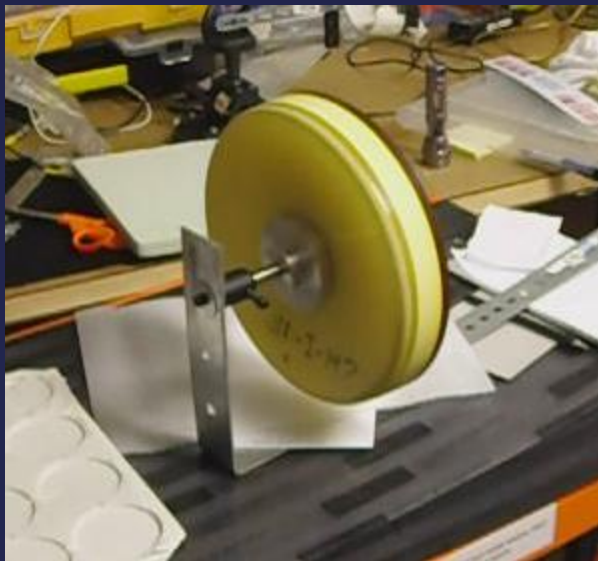
OTF Designs – Starstone 8" $f/2.25$

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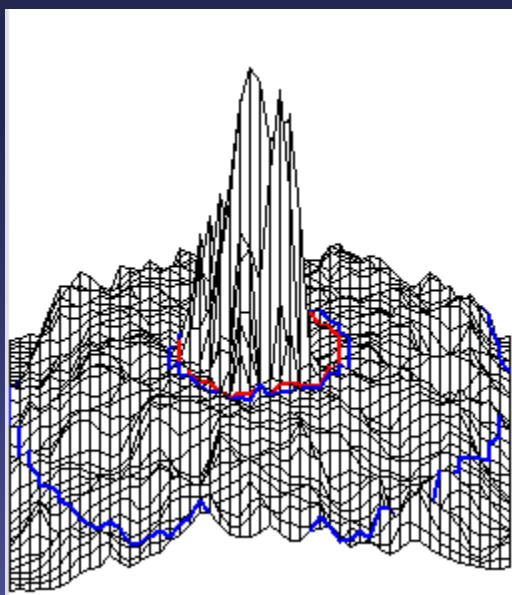
■ Mirror 0001A 8" $f/2.25$

Lander 10" epoxy $f/3.7$ No. J1R-I-147



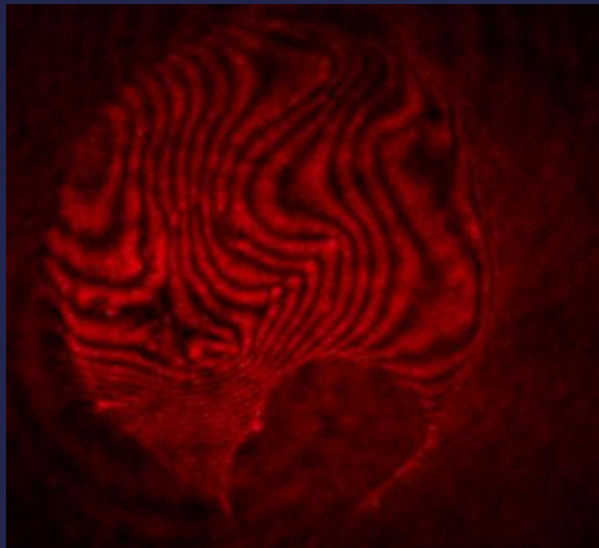
3-layer, weight – 2lbs.

5-in. mask best focus at RoC



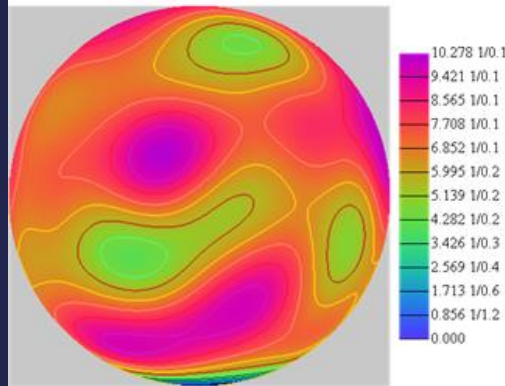
	16 pixel dia. "core"	50 pixel dia. "disk"	Total
Pixel counts	22564	101318	123882
Encircled energy	18.2%	91.8%	100%
PSF diameter	0.085 <u>milliradians</u> 3 arc min.	0.27 <u>milliradians</u> 9 arc min.	
RMS surface slope (S_{rms})	0.018 <u>milliradians</u> (1.3 waves/radius)		

Lander 10" f/3.7 No. J1R-I-147

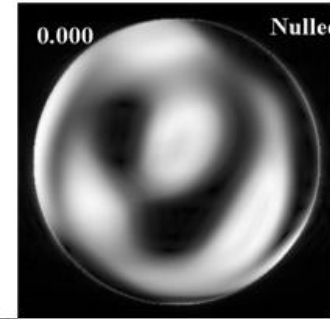


iGram of central 3.125"

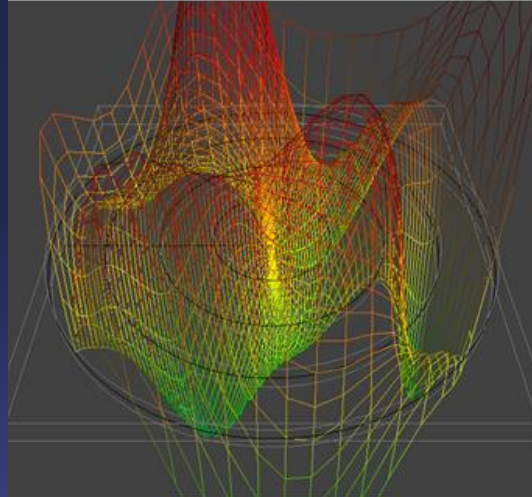
Wavefront error in Waves at 550nm RMS: 1.362 Strehl: 0.000 CC:-0.630



Mirror Default Igram Wavelength: 632.0nm
 Diameter = 79.38 mm
 ROC = 1879.60 mm
 Best Conic = -0.650 Desired Conic: -1.00
 Strehl = 0.000 Artificial Null: 0.025
 rms wavefront = 1/0.7 1.362

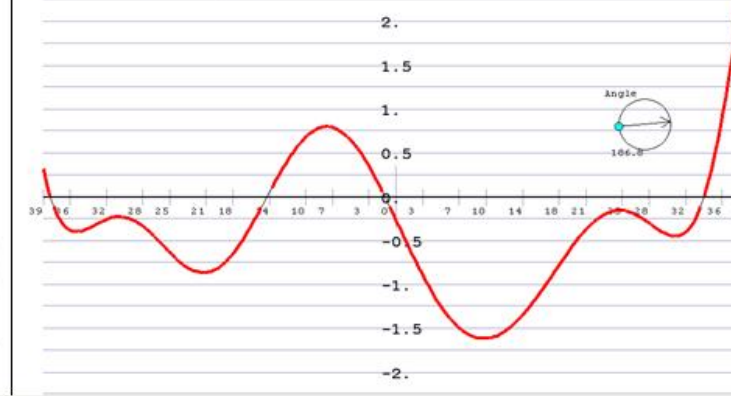


Zernike Terms	(Wyant)	WaveFront RMS	
Piston	9.410	10.813	Disabled
X Tilt	7.670	4.407	Disabled
Y Tilt	-4.482	2.575	Disabled
Defocus	1.877	1.245	Disabled
X Astig	-3.411	1.600	Disabled
Y Astig	1.263	0.592	Disabled
X Coma	-1.259	0.511	Disabled
Y Coma	-2.487	1.010	Disabled
Spherical	0.009	0.004	
X Trefoil	0.515	0.209	
Y Trefoil	0.840	0.341	
X 2nd Astig	0.844	0.307	
Y 2nd Astig	1.085	0.394	
X 2nd Coma	-0.157	0.052	
Y 2nd Coma	2.251	0.747	
2nd Spherical	0.181	0.078	
X Tetrafoil	-0.439	0.160	
Y Tetrafoil	0.479	0.174	
2nd X Trefoil	0.668	0.221	
2nd Y Trefoil	-1.498	0.497	
3rd X Astig	0.276	0.085	
3rd Y Astig	-1.133	0.348	
3rd X Coma	1.013	0.291	
3rd Y Coma	-0.425	0.122	
3rd Spherical	-0.056	0.022	



Wavefront Error in waves at 550nm

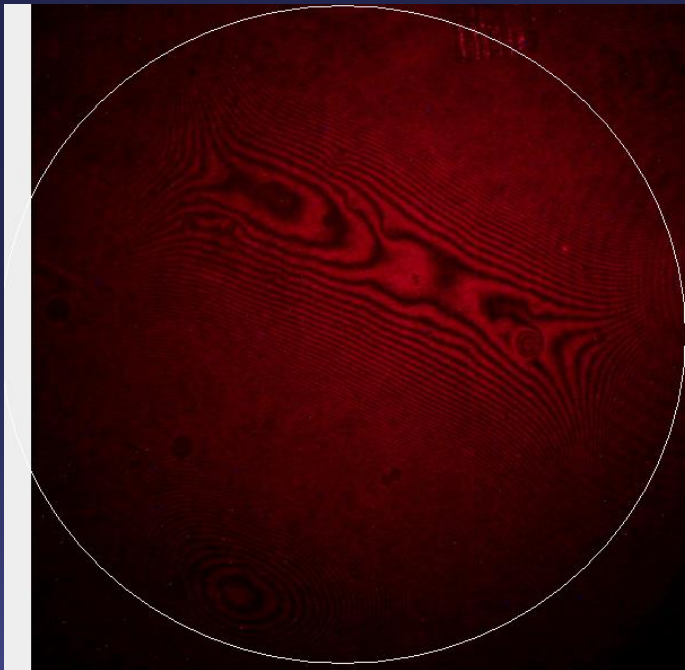
Strehl = 0.000 rms wavefront = 1/ 0.7 Waves Best Conic = -2.750 186.04



Lander 11" $f/1.75$ No. KLB-157 (rotated)



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Central 7.75" rotated CCW 90 deg.

Artificial Star PSF

- Hubble Optics 5-star flashlight used for illumination. The apertures are precision holes of 50/100/150/200/250 microns.
- Mirror 8" Starstone $f/2$ @ 11-m



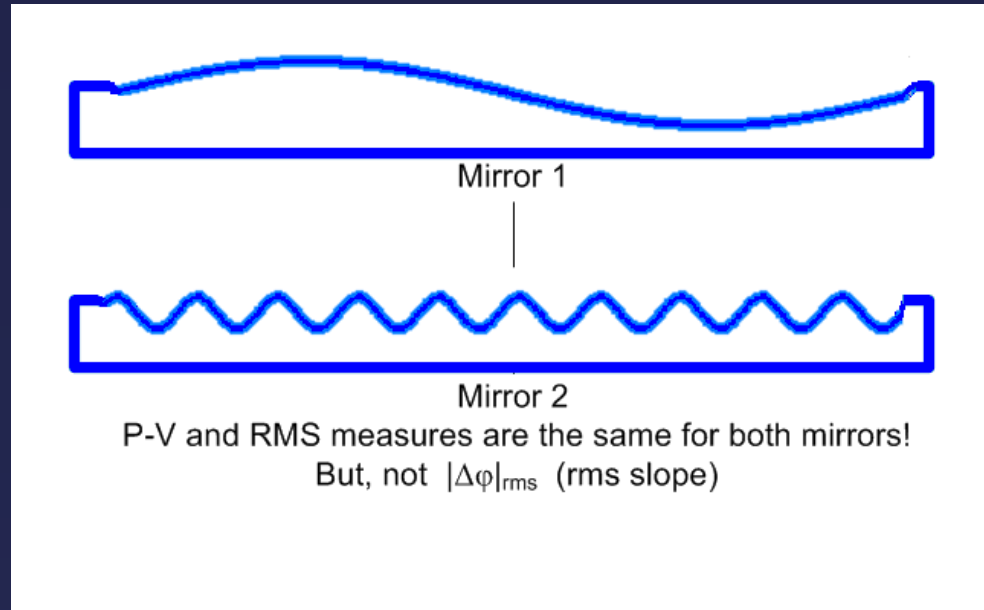
180" – no correction



25" – with correction



RMS Slope Characterization

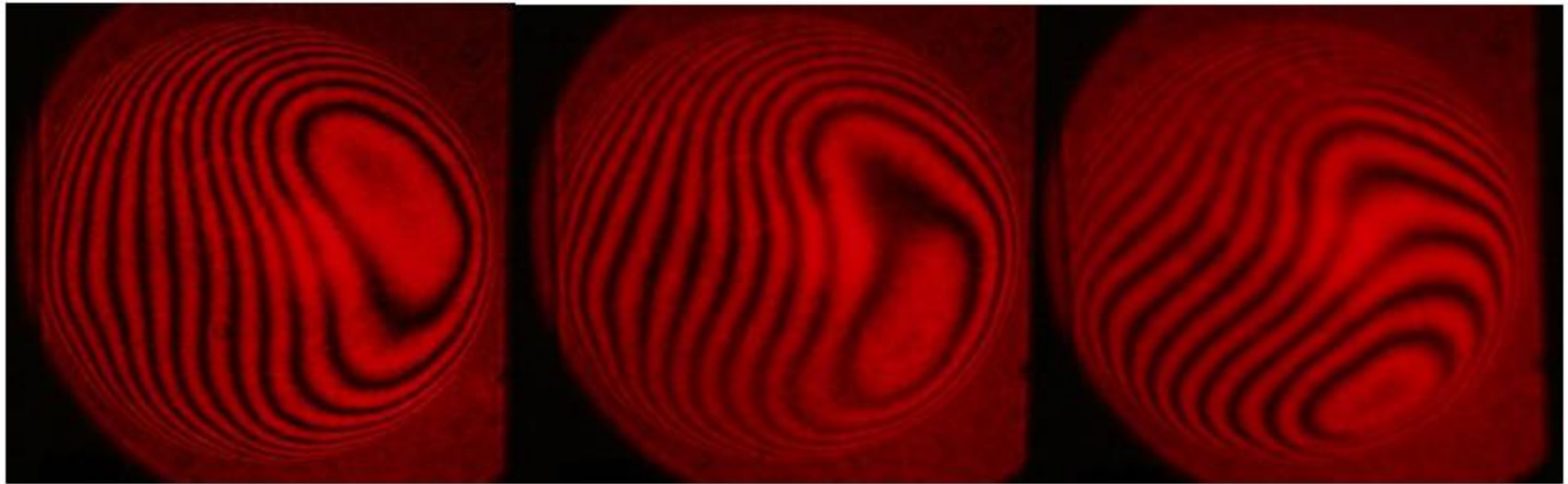


- Traditional quantification such as P-V and Strehl Ratio may not be helpful for light buckets

PSF size from slope error & aberrations

- ***FWHM spot size = $4.70 \times S_{rms}$***
 - *Where S_{rms} is the rms slope error*
- ***FWHM spot size (arc sec) $\approx 10^6 E / D$***
 - *Where D is the aperture, $E \sim$ peak aberration present*
- ***Example:***
 - One wave of astigmatism in the visible on a 1-m mirror corresponds to about an arc second *FWHM* spot (and vice versa)
 - But note higher order aberrations are much worse!

CTE - Starstone (8")



7:32:26pm

7:32:54pm

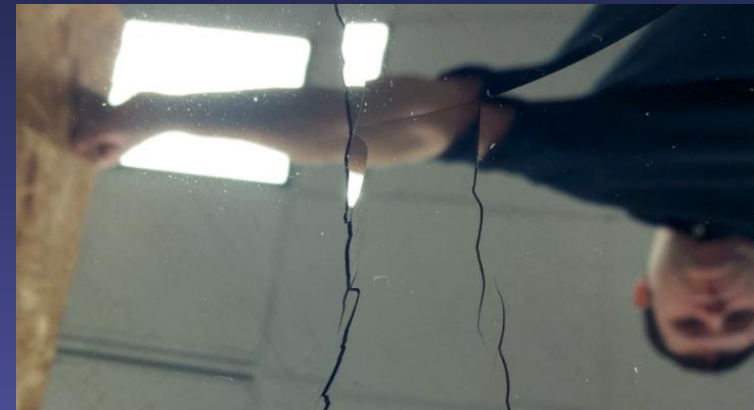
7:33:52pm

- Cooling after 30 sec. warming with heat gun

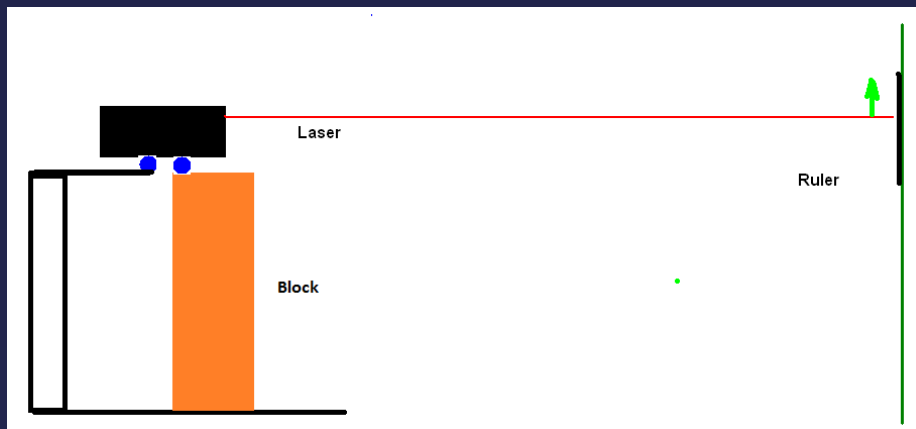
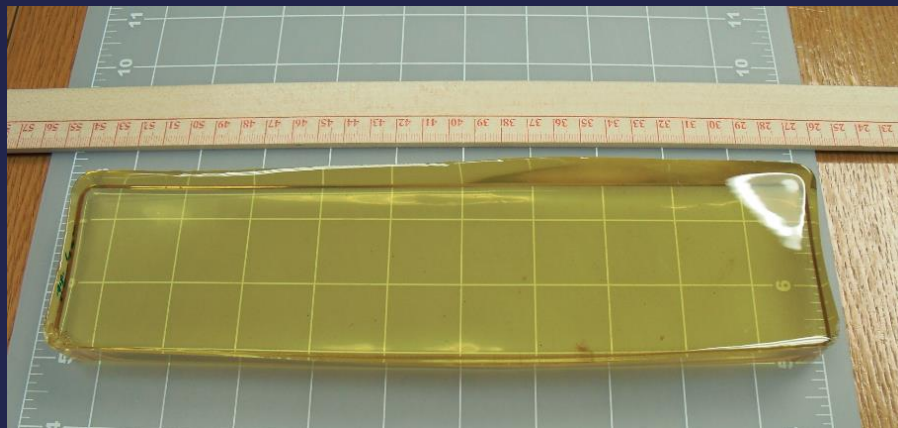
CTE Part II¹⁴



- Lander 1-m after night in cold weather



Measuring CTE



$$CTE = \frac{\Delta h}{H \Delta T} \quad \text{where } H \text{ is the block height and}$$

$$\Delta h = \frac{\text{Max deflection} \times \text{Rod separation}}{\text{Distance to wall}}$$

	<i>Max Def.(cm)</i>	Δh (mm)	H (mm)	ΔT ($^{\circ}C$)	CTE (ppm/ $^{\circ}C$)
Sample 1	17.1	0.60	265	37.2	60.8

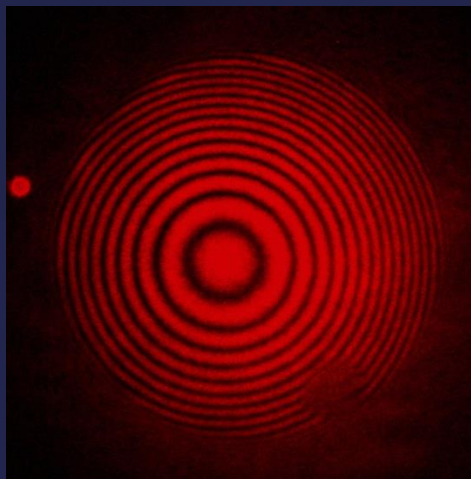
Coatings and Reflectivity Tests

- Cold silvered (4) – verify Strehl
- Extra Thin Peacock Labs Permalac coated (3)
- Flats (2 each) – test reflectivity

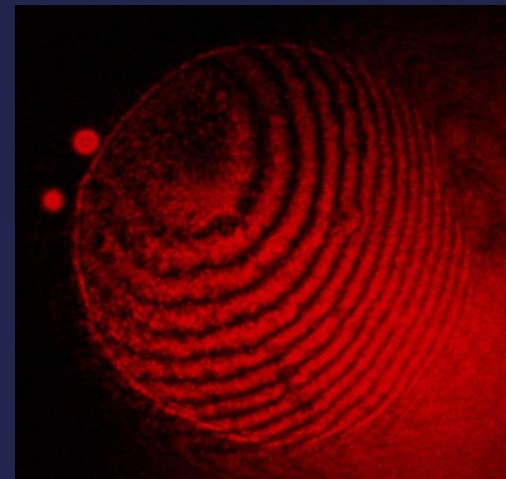


Coating Tests II

- Just silvered – very fine (confirmed)
- Extra Thin still not thin enough



Silvered



Extra Thin Permalac

Mirror #	BEFORE COATING		AFTER SILVERING	
	RMS Wavefront Error (waves @ 550nm)	Strehl Ratio	RMS Wavefront Error (waves @ 550nm)	Strehl Ratio
No overcoat				
20	0.031	0.963	0.001	0.962
22	0.120	0.567	0.071	0.821
24	0.073	0.812	0.065	0.847
26	0.080	0.778	0.099	0.680
Extra-thin overcoat				
5	0.042	0.933	0.088	0.735
21	0.085	0.753	0.199	0.211
36	0.083	0.760	0.285	0.040

Contact and further information

- Email: bholenstein@gravic.com
- Gravic Labs Papers (source for many pictures):
<http://www.gravic.com/graviclabs/rd/astronomy/papers.html>
- Alt-Az Telescope Initiative Website: www.AltAzInitiative.org
- Bath interferometer:
http://starryridge.com/mediawiki-1.9.1/index.php?title=Bath_Interferometer
- Yahoo Discussion Groups:
<http://groups.yahoo.com/group/AltAzInitiative>
<http://groups.yahoo.com/group/Interferometry>