

# Gravic Light Bucket

## Astronomy Projects 2010

*Bruce D. Holenstein, Robert H. Koch, Richard J. Mitchell,  
Dylan R. Holenstein, Alexander D. Thompson,  
Alexander J. Demirjian, Michael D. Holenstein,  
Garth R. Boyer*

**Gravic, Inc.**

**Alt-Az Initiative Portland IV Workshop, 7/31-8/1, 2010**

# Topics

- Research Opportunities
  - Occultations & other topics
- Light Bucket Astronomy
  - Light bucket theory
  - Relative SNRs
- Optical Technologies
  - Light bucket mirrors
  - Correctors
  - Evaluations of other new technologies
- Instrumentation
  - Area and diaphragm detectors

# Topics

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  - **Occultations & other topics**
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# Research Opportunities

- Occultations
- Intensity Interferometry
- High-precision photometry
- Spectroscopy
- Polarimetry
- And many other astronomical areas...

# Occultations

- IOTA – focuses on timing events
- Occultation sources
  - Lunar
  - Asteroids
  - Other solar system
- KBO opportunity

*Occultation*

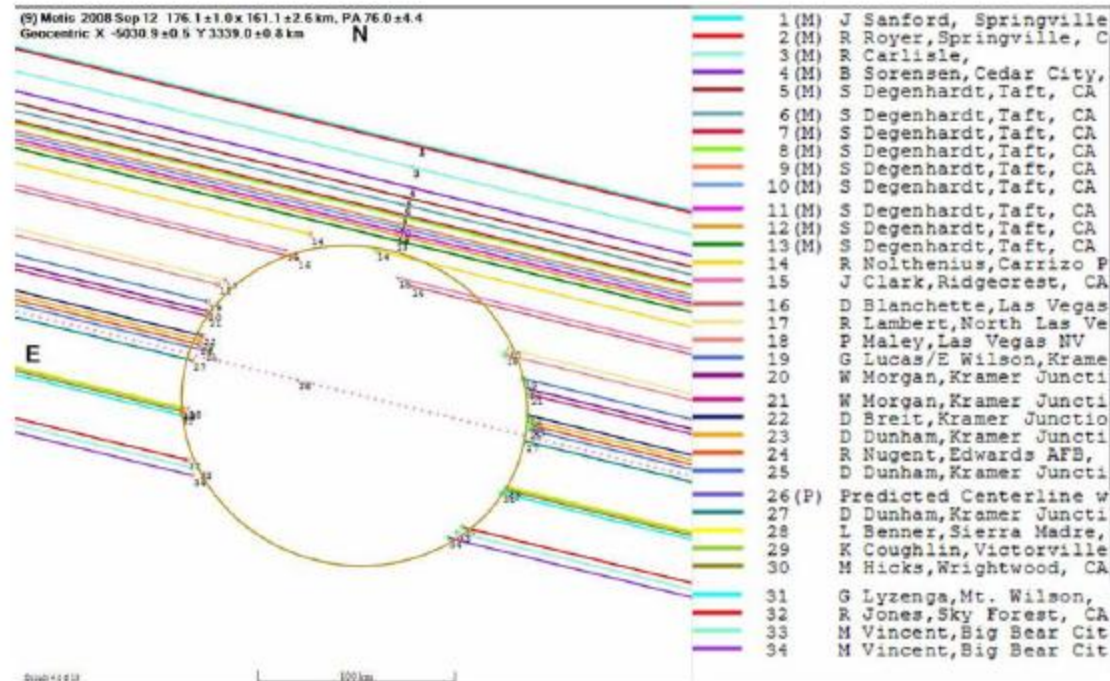


*Newsletter*

Volume 14, Number 1

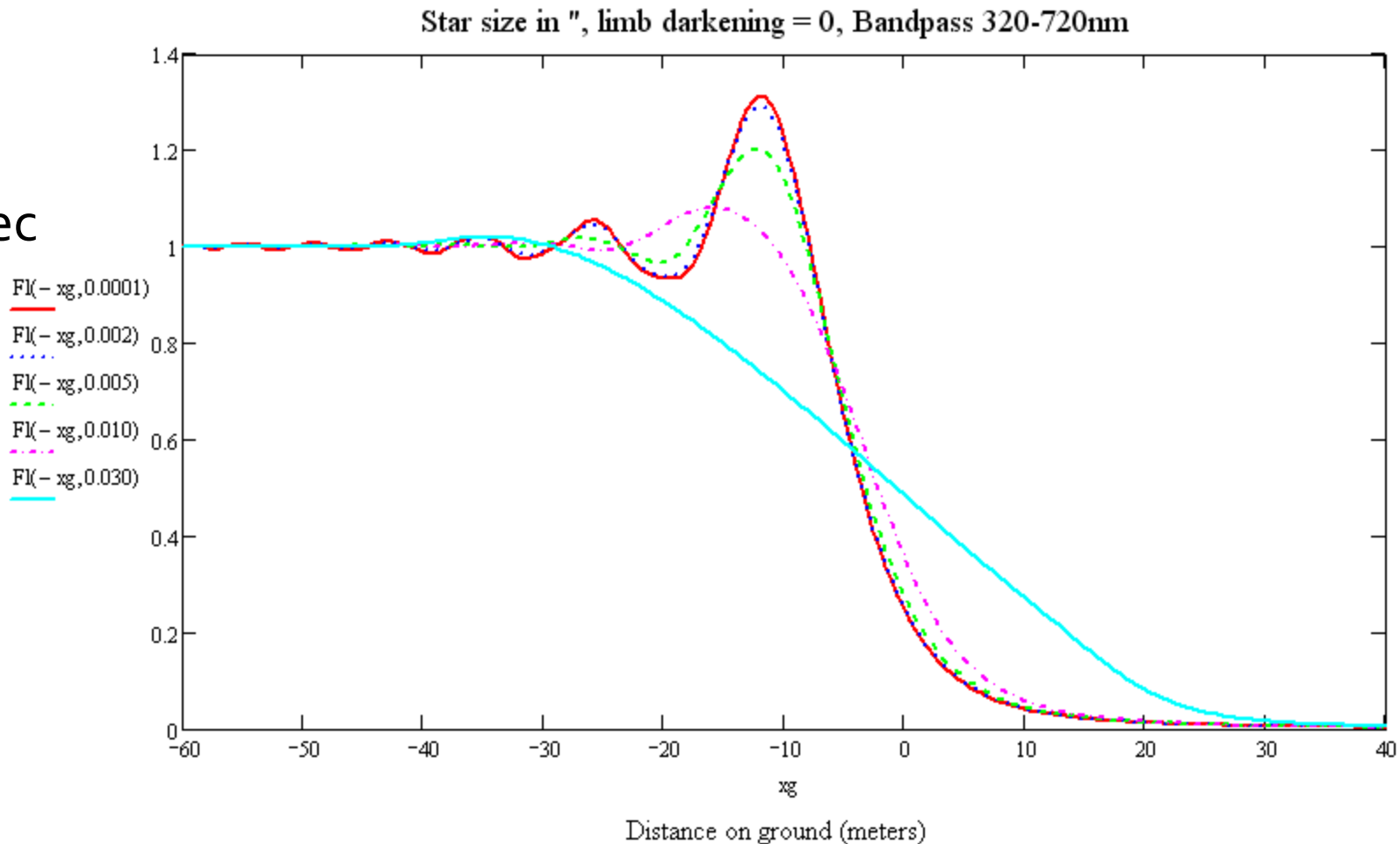
January 2009

\$5.00 North Am./\$6.25 Other

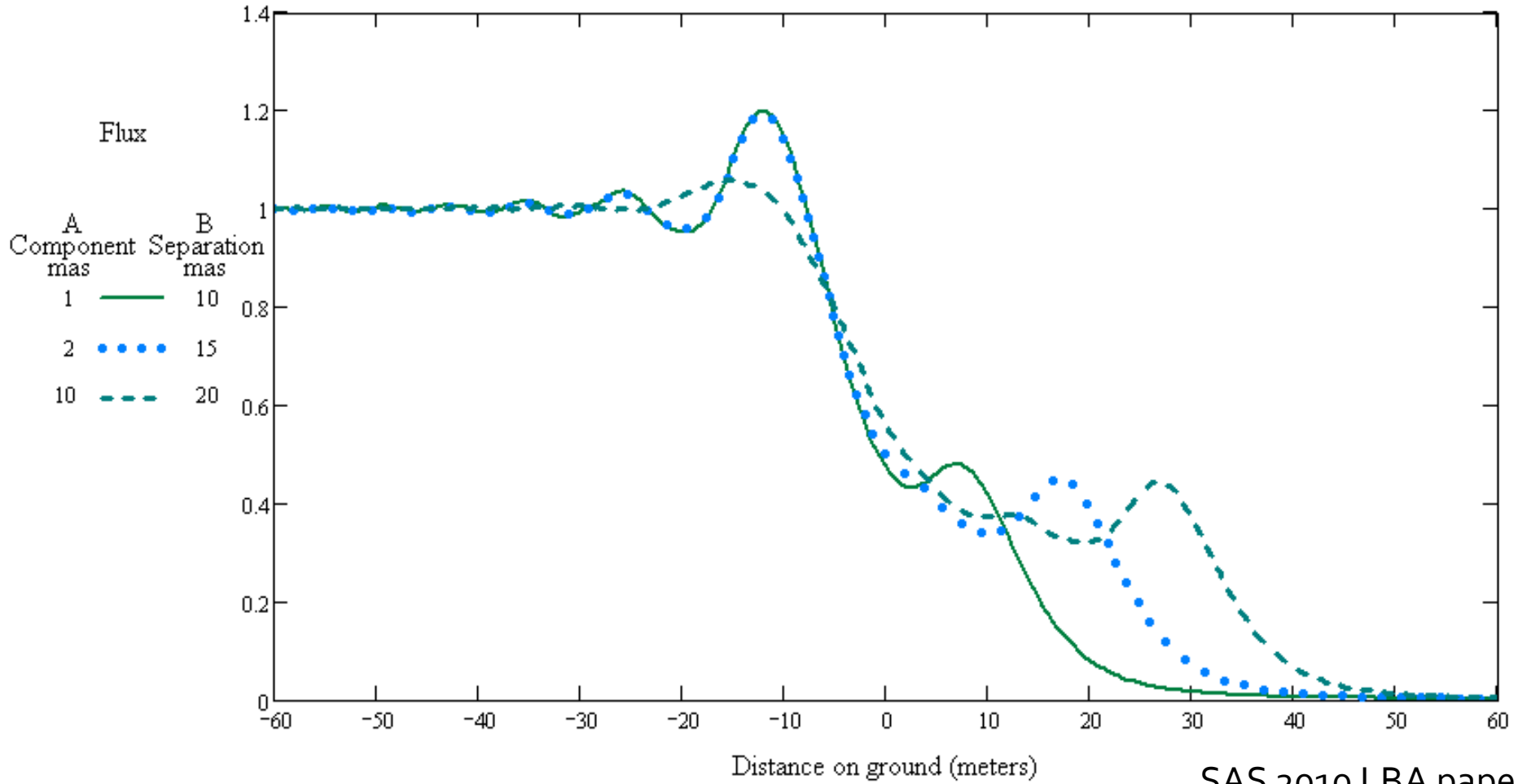


# Lunar Occultations

- Single Star
- Moon  $\sim 0.3''/\text{sec}$



# Lunar Occultations II



# Lunar Occultations III

- IOTA Software Tools
  - Occult4, Occult Watcher, LiMovie, Tangra
  - Demo (time permitting)
- Detectors needed:
  - Fast area or diaphragm-limiting
  - Longer wavelengths (NIR) advantages



# Sample Event

**Lunar occultation predictions**

with Prediction ... Mag limit adjustment... 3-day weather forecast Help Exit

1. Select site for predictions: Use home [BDH sites.site], Set home [-122.5 to -72.9, 33.3 to 45.2], Use single [Malvern-Gravic], Filter search to sites in file [ ]

2. Star catalogue: [XZ], [XZ < mag 9], [XZ < mag 7], [XZ < mag 4], [XZ]

3. Objects: [Stars], [Planets], [Asteroids]

4. Set UT dates: Year [2010], Month [Jun], Day [18], Starting at [-6 hrs], [0 hrs], [+6 hrs], [+12hrs]

5. Events for Site: [Occultations], [Grazes], [Multi-site for 1 star], [World map]

6. Events anywhere

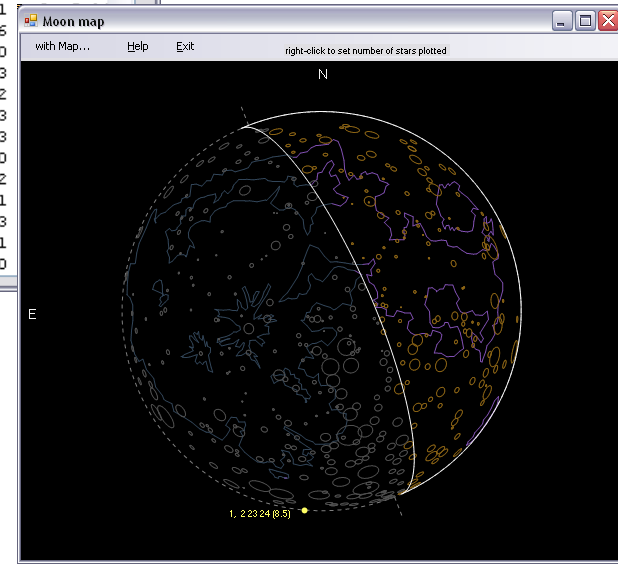
Short Output [ ], List grazes only [ ], Doubles only [ ]

[2010 Jun 18]

Right-click on prediction for further options

10 Jun 18	1 25 15 r	X119144	11.1 10.8	37+	75	-9 30 245	-21S	225 181 203	+1.9 +6.7	+3.4+2.0	.109 -103	10 42 13.9	2 10 4
10 Jun 18	1 31 43 r	118445 G0	9.3 9.0	37+	75	-10 29 246	-37N	347 302 325	+1.9 +6.7	+0.2-2.6	.346 135	10 42 55.5	2 35 57
10 Jun 18	1 34 13 d	X 34285 K2	10.6 10.0	37+	75	-10 29 246	79N	103 59 82	+1.9 +6.7	+1.0-1.5	.466 18	10 44 18.6	2 15 43
10 Jun 18	1 41 47 r	X119157	11.3 11.0	37+	75	-11 27 248	-81S	285 240 264	+1.9 +6.7	+0.9-1.5	.478 -164	10 42 24.6	2 21 40
10 Jun 18	1 49 42 d	X119272	11.5 11.0	37+	75	26 249	79N	103 57 81	+1.9 +6.7	+0.9-1.5	.475 18	10 44 45.3	2 11 52
10 Jun 18	1 51 6 d	X119280	11.1 10.7	37+	75	26 249	67N	90 44 69	+1.9 +6.7	+1.0-1.3	.432 30	10 44 49.2	2 14 55
10 Jun 18	2 9 48 d	X119307	10.2 10.0	37+	75	23 253	76N	100 53 79	+1.8 +6.7	+0.8-1.5	.482 20	10 45 21.2	2 7 23
10 Jun 18	2 11 22 r	X119200	11.4 11.0	37+	75	22 253	-71S	275 227 253	+1.8 +6.7	+0.8-1.4	.466 -155	10 43 14.6	2 11 7
10 Jun 18	2 12 10 r	118447 K0	9.3 8.8	37+	75	22 253	-74S	278 230 256	+1.8 +6.7	+0.7-1.4	.478 -158	10 43 16.5	2 11 46
10 Jun 18	2 18 19 r	118452cF2	8.3 8.1	37+	75	21 255	-73S	277 229 255	+1.8 +6.7	+0.7-1.4	.479 -157	10 43 27.4	2 9 53
118452 is double: ** 8.5 9.1 0.10" 190.0**													
118452 has been reported as non-instantaneous (0Cc 412). Observations are highly desired													
10 Jun 18	2 23 24 D	118468 G5	8.5 8.3	37+	75	20 255	29S	175 127 154	+1.8 +6.7	+0.0-2.9	.293 -56	10 44 47.3	1 50 23
10 Jun 18	2 24 41 d	X119309	11.5 11.2	37+	75	20 255	61S	143 95 122	+1.8 +6.7	+0.4-2.1	.478 -24	10 45 23.1	1 53 23
10 Jun 18	2 31 47 d	X 16131 F2	10.1 9.9	37+	75	19 256	64N	88 39 66	+1.8 +6.7	+0.7-1.3	.450 32	10 46 2.1	
10 Jun 18	2 34 54 r	X 34285 K2	10.6 10.0	37+	75	18 257	-66N	317 269 296	+1.8 +6.8	+0.4-2.0	.504 162	10 44 18.6	
10 Jun 18	2 41 49 d	X119346	11.2 10.9	37+	75	17 258	52N	76 27 54	+1.8 +6.8	+0.7-1.0	.392 43	10 46 19.0	
10 Jun 18	2 43 25 d	118486 G5	9.2 8.7	37+	75	17 258	42N	66 17 44	+1.8 +6.8	+0.8-0.7	.325 53	10 46 18.3	
10 Jun 18	2 45 30 r	X119280	11.1 10.7	37+	75	16 259	-55N	329 280 307	+1.8 +6.8	+0.2-2.2	.464 150	10 44 49.2	
10 Jun 18	2 49 17 r	X119272	11.5 11.0	37+	75	15 260	-67N	317 267 295	+1.8 +6.8	+0.3-2.0	.514 162	10 44 45.3	
10 Jun 18	2 56 57 r	118468 G5	8.5 8.3	38+	76	14 261	-38S	242 193 221	+1.8 +6.8	+0.7-0.6	.307 -124	10 44 47.3	
10 Jun 18	3 2 49 d	X119378	11.0 10.6	38+	76	13 261	51N	75 25 53	+1.8 +6.8	+0.5-1.0	.402 43	10 46 59.0	
10 Jun 18	3 7 23 r	X119307	10.2 10.0	38+	76	12 263	-66N	317 268 296	+1.8 +6.8	+0.2-2.0	.521 160	10 45 21.2	
10 Jun 18	3 18 56 r	X119309	11.5 11.2	38+	76	10 264	-70S	273 223 252	+1.8 +6.8	+0.3-1.4	.515 -156	10 45 23.1	
10 Jun 18	3 19 43 r	118486 G5	9.2 8.7	38+	76	10 264	-34N	350 300 328	+1.8 +6.8	+0.0-2.6	.341 127	10 46 18.3	
10 Jun 18	3 22 55 r	X 16131 F2	10.1 9.9	38+	76	9 265	-55N	328 279 307	+1.8 +6.8	+0.1-2.1	.482 149	10 46 2.1	
10 Jun 18	3 25 38 r	X119346	11.2 10.9	38+	76	9 265	-44N	340 290 318	+1.8 +6.8	+0.0-2.3	.416 137	10 46 19.0	

- Predictions based on location and elevation



# Video Equipment



# N18 on IPI 393 GEM





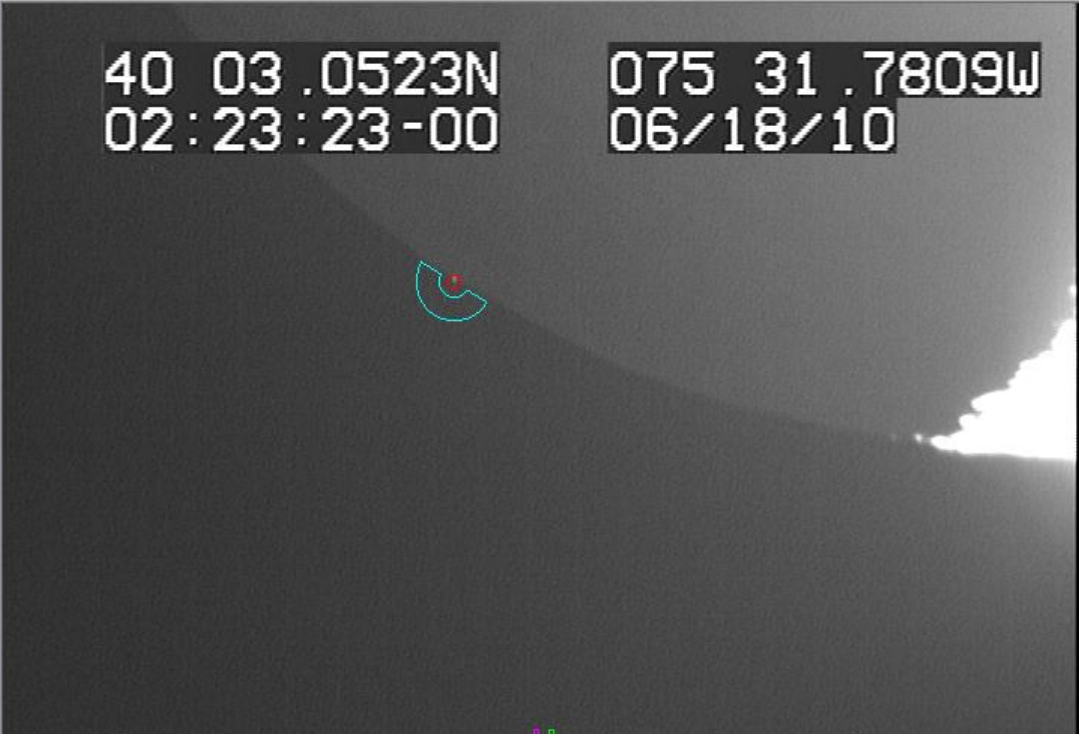
# Occultation Video

Light Measurement Tool for Occultation Observation using Vidieo Recorder [Limovie 0.9.29b]

File Edit Option

40 03 .0523N  
02 : 23 : 23 -00

075 31 .7809W  
06 / 18 / 10



Limovie File Format (for Ver.0.9.26 later)  
 "FileName : E:\astronomy\video\2010-06-1718 4 c  
 "Video System : — , FrameRate=30.30"  
 ,"Time",,"Centre of",,"End of",,"Result",,"Obje  
 ,"Detect",,"VTI",,"Frame",,"Frame",,"Sound",,"Mea  
 "No.",,"Signal1",,"Signal2",,"H",,"M",,"S",,"Frame"  
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Current Frame: 523

Measurement Value: BK G/Frame 71.6

Star Even: 463.1

Star Odd: 436.6

Star Frame: 899.6

Color Value: [ ]

Position Center Tracking: X=300, Y=179

Half Flux Diameter: 4.888

Star Tracking: Sync-APT checked, Radius 7, Threshold 50

Speed Control: 0 Delay (Sec) 1.0

Form of BKG-Area: Avoid Sunlit Face

Number of Pixels / Radius: Even 32, Odd 37, Frame 69

End Time of Field Exposure (Field1=Centre of Frame)

h	m	s [Field1]	[Field2]	Threshold	S1	S2
				80		<input checked="" type="checkbox"/> K/W

Audio Channel Display: [ ] Star Image [3D]

File: E:\astronomy\video\2010-06-1718 4 c

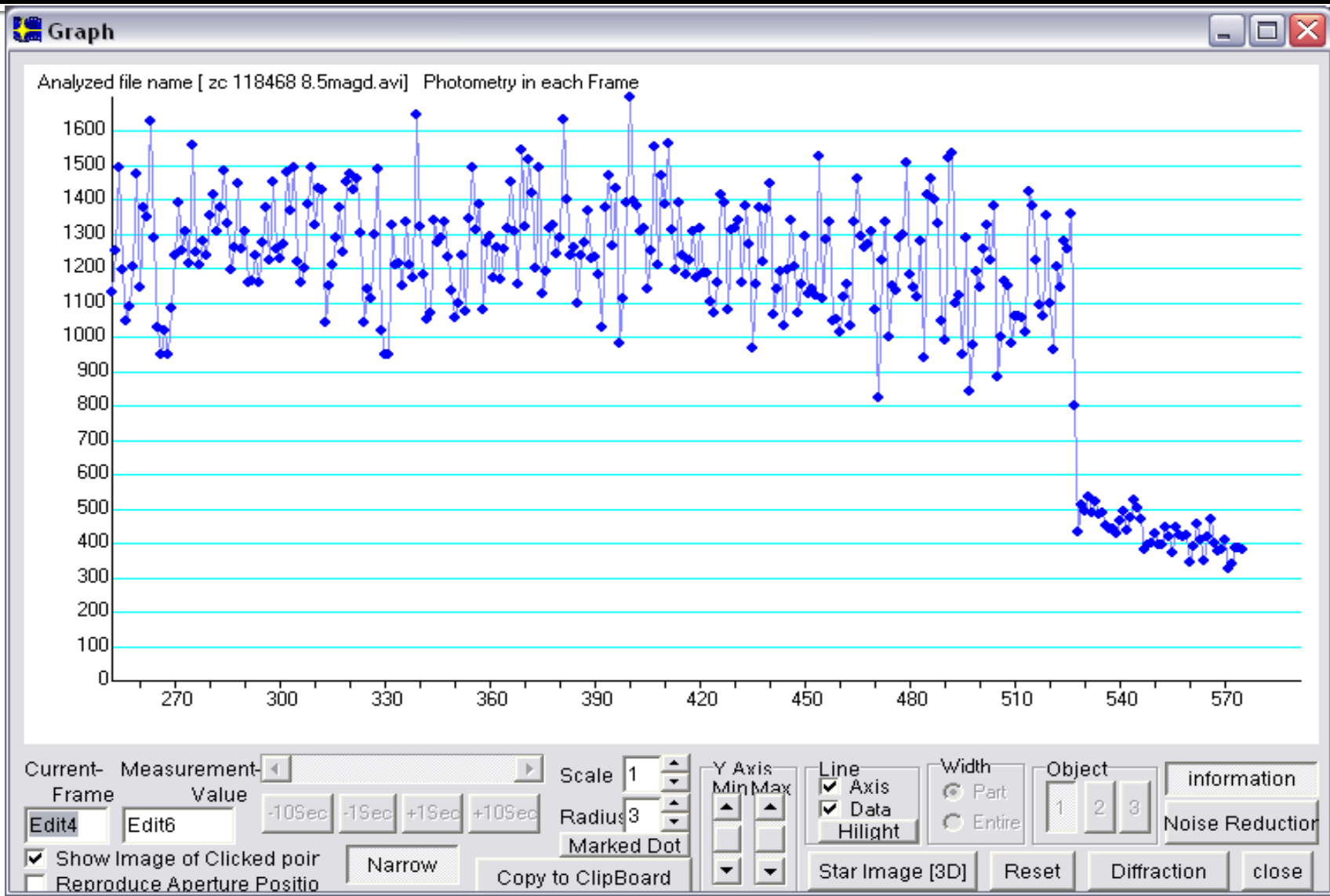
AVI File Open Load CSV Exit

Measurement / View Option: Field Show Interval 1, Frame Rate from VFW 30.30

Field Order:  Even first  Odd first

Current Object: 1 2 3

# Light Curve



# Lucky imaging with Light Bucket

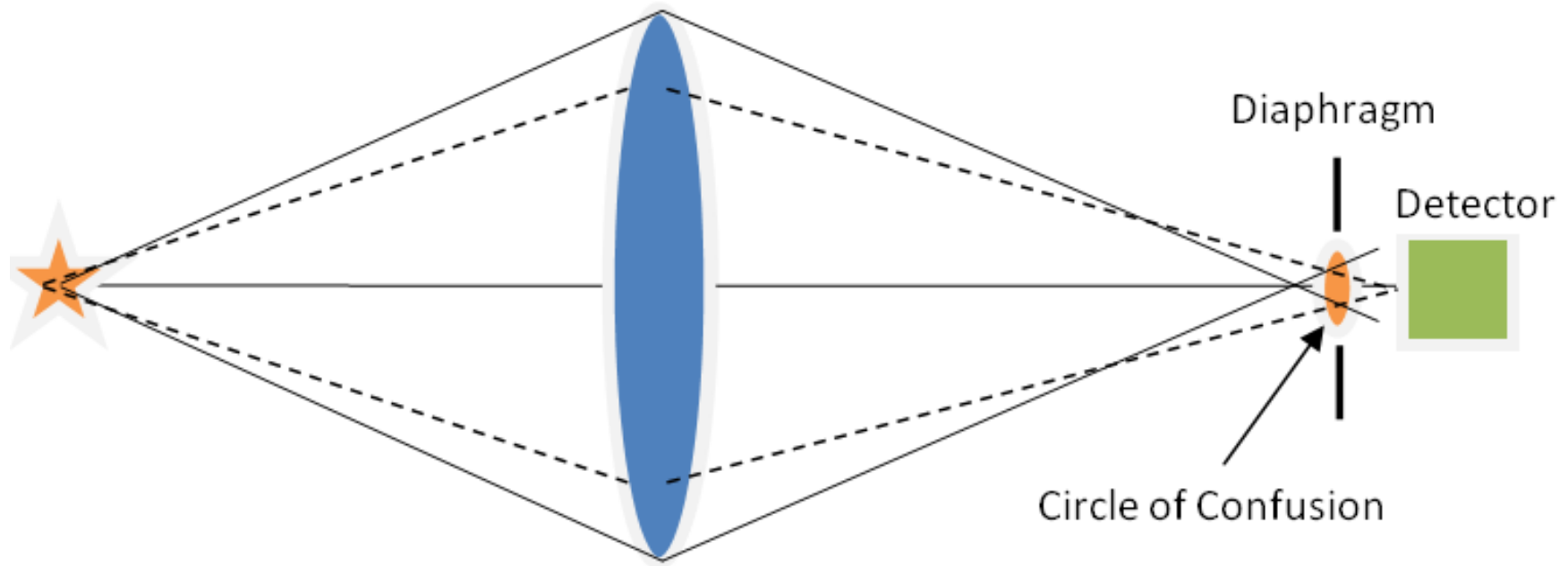
- Keep just 2%, but which?
  - Use atmosphere to conjugate the mirror aberrations
- Defocused moon video from C8 SCT processed with Registak5 seems to work



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  - **Relative SNRs**
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  - Correctors
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# Circle of Confusion

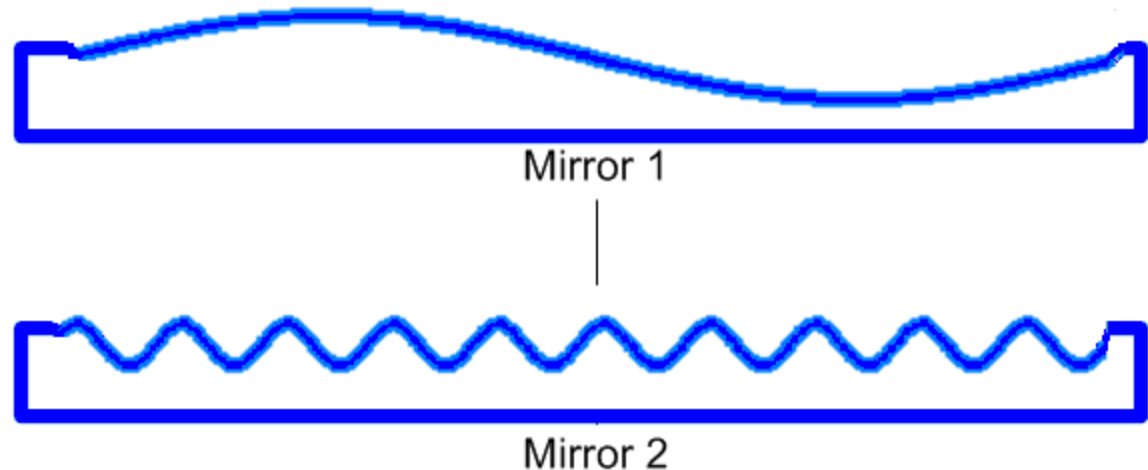


- Circle of Confusion = blur spot at focal plane
- Diaphragm = circular isolator before the detector



# Aberration Characterization I

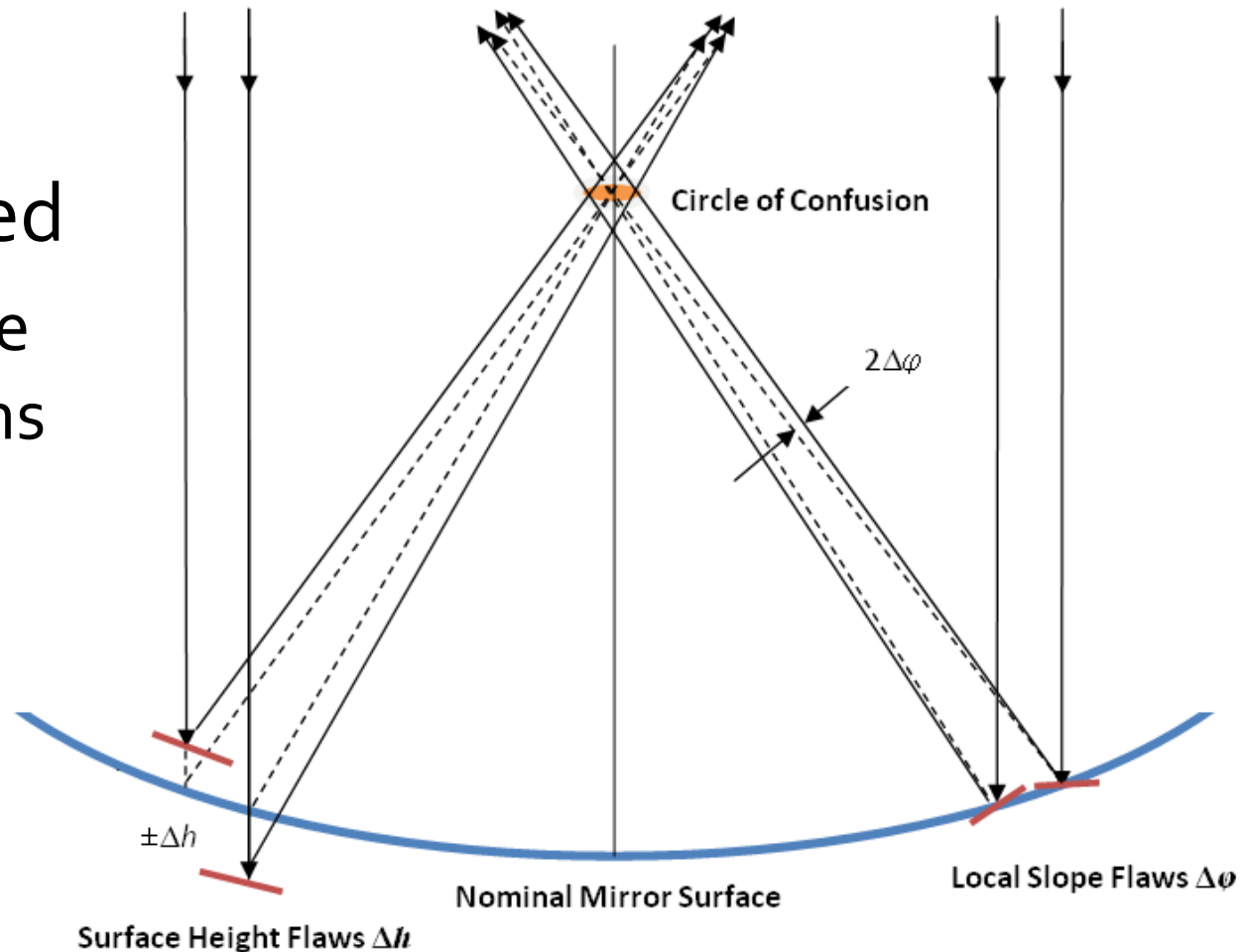
- Tools were needed to characterize progress and failure in our work
  - Traditional quantification such as P-V and Strehl Ratio were not helpful



P-V and RMS measures are the same for both mirrors!  
But, not  $|\Delta\phi|_{\text{rms}}$  (rms slope)

# Aberration Characterization II

- Two aberration types considered
  - Random surface height variations
  - Random local slope problems



# Aberration Characterization III

- Diameter of CoC from surface height flaws:

$$d_{CoC, surface\ height}(n) \approx 0.5n\sigma/f$$

- Diameter of CoC from local slope flaws:

$$d_{CoC, local\ slope}(n') \approx 4n'F |\Delta\phi|_{rms}$$

where  $f$  is the focal ratio,  $F$  is the focal length, and the  $n$  and  $n'$  multipliers determine the encircled flux fraction

# Aberration Characterization IV

- Zernike wavefront representation,  $W(\rho, \theta)$ , is used for the estimation of  $\sigma$  and  $|\Delta\phi|_{rms}$

- **1** 
$$W(\rho, \theta) = \sum_j a_j Z_j(\rho, \theta)$$

- **2** 
$$\sigma_W^2 = \langle W^2(\rho, \theta) \rangle - \langle W(\rho, \theta) \rangle^2 = \sum_{j=2} a_j^2$$

- **3** 
$$\nabla W(\rho, \theta) = \frac{\delta W}{\delta \rho} \mathbf{e}_\rho + \frac{1}{\rho} \frac{\delta W}{\delta \theta} \mathbf{e}_\theta$$

- **4** 
$$|\Delta\phi|_{rms} = \frac{\|\nabla W\|_{rms}}{D/2}$$

# Aberration Characterization V

- Solving for the spot size gives a useful rule of thumb:

$$\text{FWHM spot size (arc sec)} = 2.35 \times 2 |\Delta\varphi|_{rms}$$

$$= 2.35 \times 4 \|\nabla W\|_{rms} / D \approx 10^6 E / D ,$$

where  $E$  is the “wavefront error,”  $D$  is the mirror diameter in the same units.

e.g., 2 waves =  $10^{-6}$ -m on 1-m mirror  $\sim$  2” FWHM

Note:  $E$  depends on the type of aberration (above holds for when rms grad norm = 0.5 (P-V), e.g., for tilt).

# Common Aberration Gradients

Zernike Gradients					
$j$	Type	Polynomial	"E" P-V	RMS Wavefront Gradient $\ \nabla W_j\ _{rms}$	Ratio RMS Grad/E
1	Piston	1	$a_1$	0	0
2	X Axis Tilt	$2\rho \cos\theta$	$4a_2$	$2 a_2$	0.5
3	Y Axis Tilt	$2\rho \sin\theta$	$4a_3$	$2 a_3$	0.5
4	Defocus (power)	$\sqrt{3}(2\rho^2 - 1)$	$2\sqrt{3} a_4$	$2\sqrt{6} a_4$	1.4
5	$45^\circ$ Astigmatism	$\sqrt{6}\rho^2 \sin 2\theta$	$2\sqrt{6} a_5$	$2\sqrt{3} a_5$	0.7
6	$0^\circ$ Astigmatism	$\sqrt{6}\rho^2 \cos 2\theta$	$2\sqrt{6} a_6$	$2\sqrt{3} a_6$	0.7
7	Y Coma	$2\sqrt{2}(3\rho^2 - 2\rho)\sin\theta$	$\frac{16\sqrt{2}}{3} a_7$	$2\sqrt{14} a_7$	1.0
8	X Coma	$2\sqrt{2}(3\rho^2 - 2\rho)\cos\theta$	$\frac{16\sqrt{2}}{3} a_8$	$2\sqrt{14} a_8$	1.0
9	$30^\circ$ Trefoil	$2\sqrt{2}\rho^3 \sin 3\theta$	$4\sqrt{2} a_9$	$4\sqrt{6} a_9$	1.7
10	$0^\circ$ Trefoil	$2\sqrt{2}\rho^3 \cos 3\theta$	$4\sqrt{2} a_{10}$	$4\sqrt{6} a_{10}$	1.7
11	Principal Spherical	$\sqrt{5}(6\rho^4 - 6\rho^2 + 1)$	$\frac{3\sqrt{5}}{2} a_{11}$	$2\sqrt{30} a_{11}$	3.2

Note: Malacara (2007) normalization

# Figures of Merit I

- How do aberrations affect the Signal-to-Noise-Ratio (SNR)?

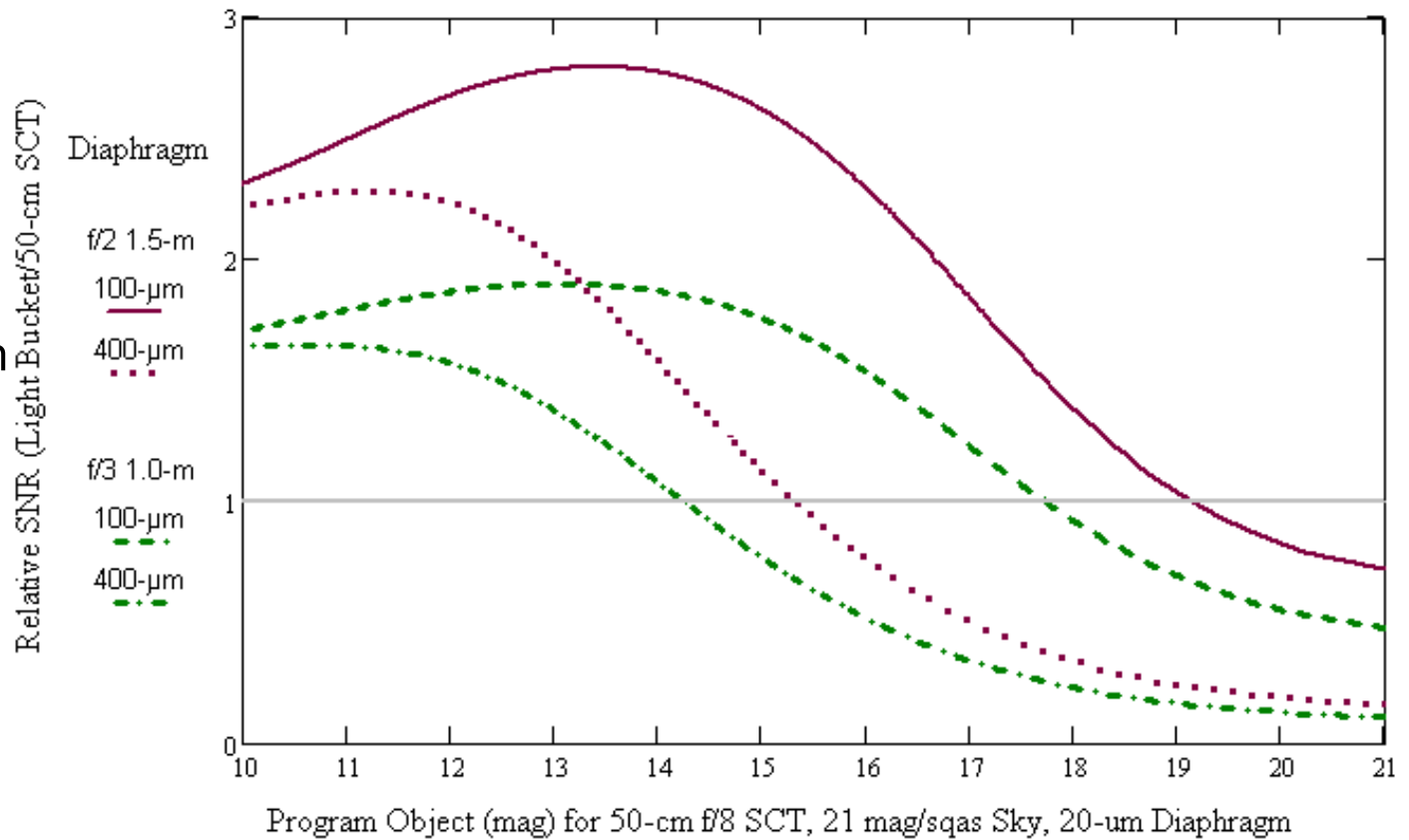
$$SNR = \frac{N_{Star+Sky} - N_{Sky}}{\sqrt{N_{Star+Sky} + N_{Sky} + N_{Detector} + S^2}}$$

where  $N$ s are counts and  $S$  models atmospheric scintillation

- Focal plane diaphragm size

# Light Bucket vs. SCT

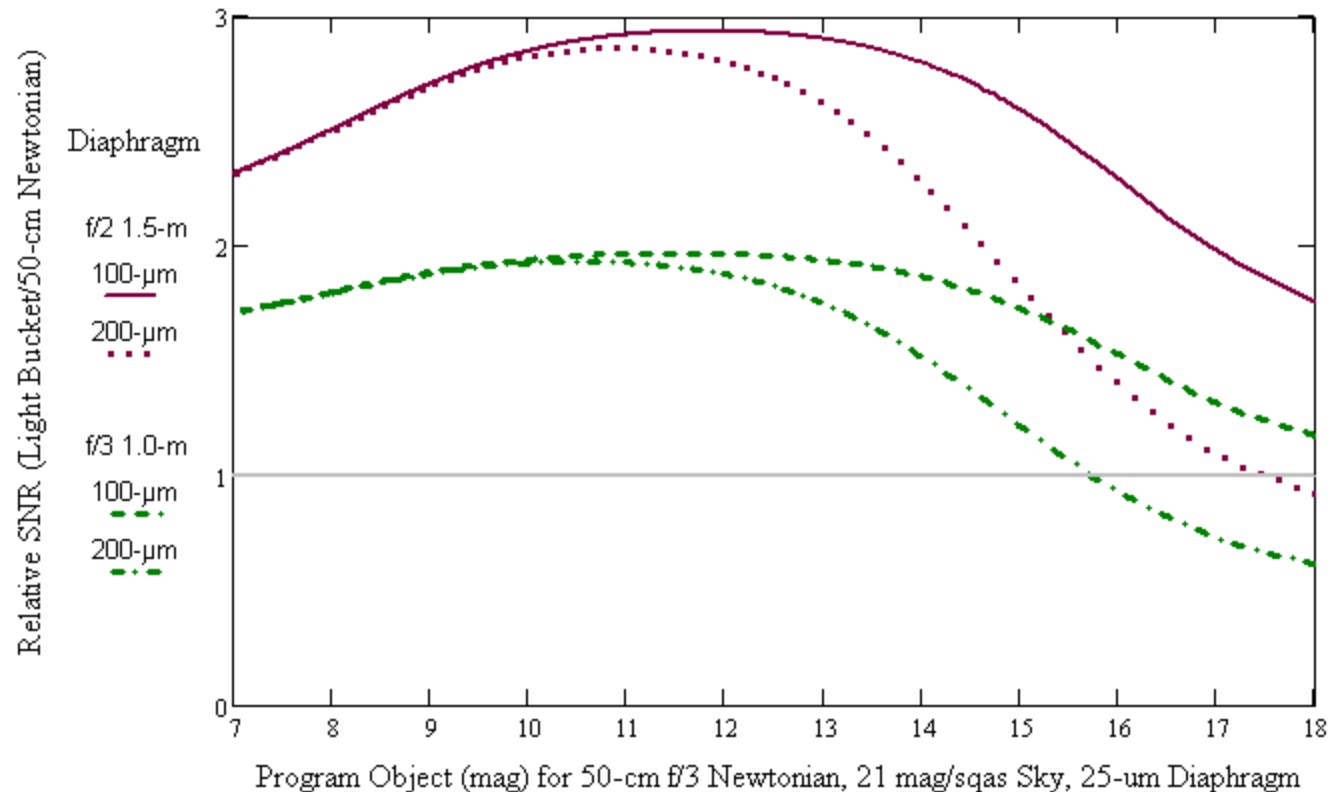
- Traditional f/8 SCT, 0.50-m mirror
- Light bucket f/2, 1.5-m & f/3, 1.0-m
- Diaphragms - 28" & 7" vs. 1" on SCT
- Scintillation at 1000-m, air-mass 1.5





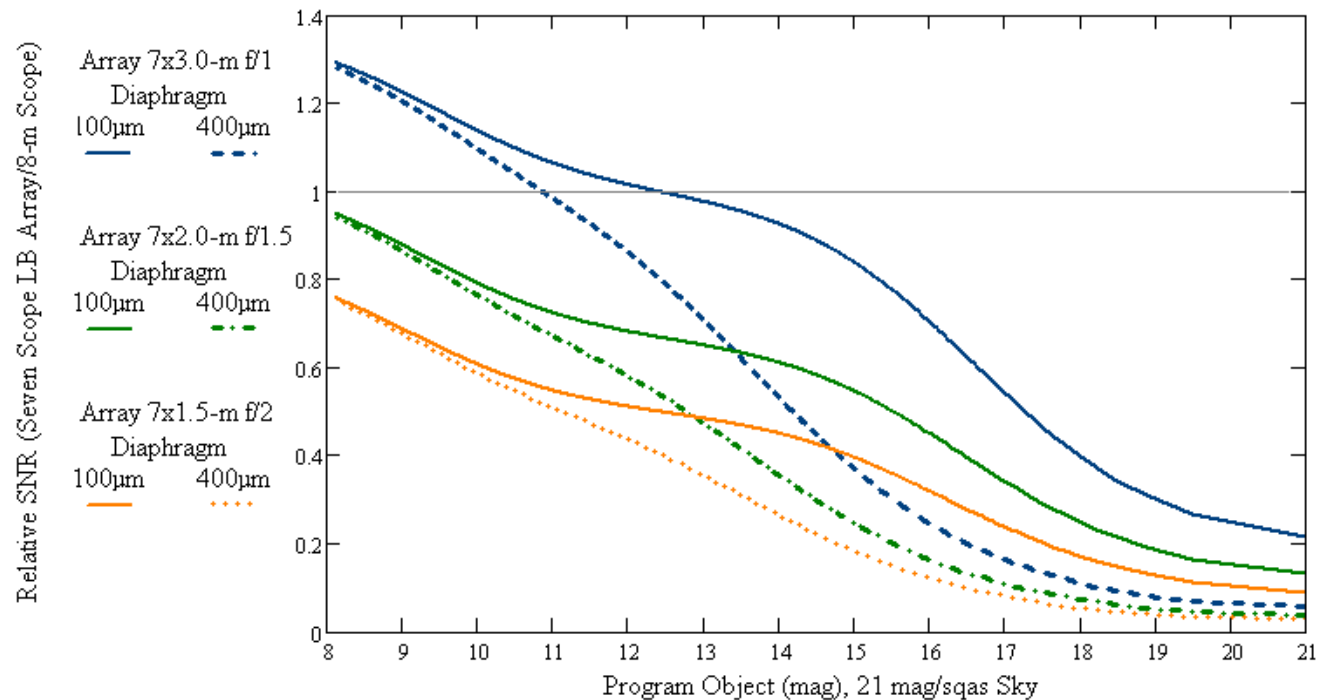
# Light Bucket vs. Newtonian

- Traditional  $f/3$  Newt., 0.50-m mirror
- Light bucket  $f/2$ , 1.5-m &  $f/3$ , 1.0-m
- Diaphragms - 28" & 7" vs. 7" on Newtonian
- Scintillation at 1000-m, air-mass 1.5



# Light Bucket Arrays

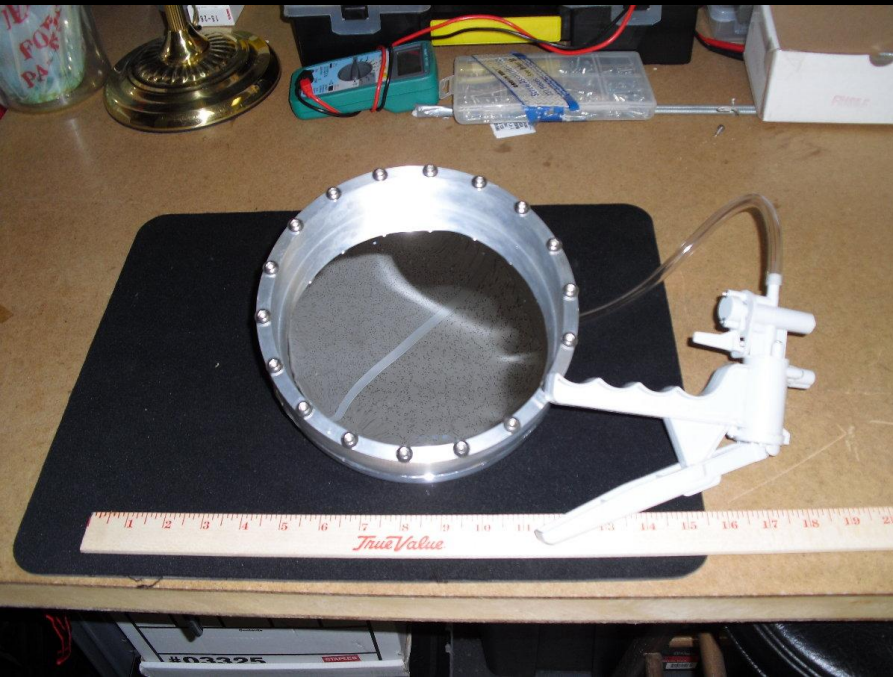
- 7 LBT arrays vs 8-m f/1 scope
- 2 relative diaphragm diameters (400, 100 vs 40 micron on 8-m)
- Scintillation at 3000-m, air-mass 1.5



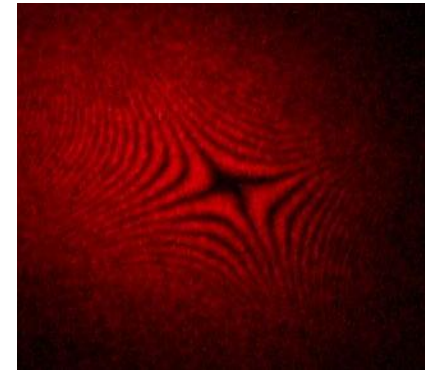
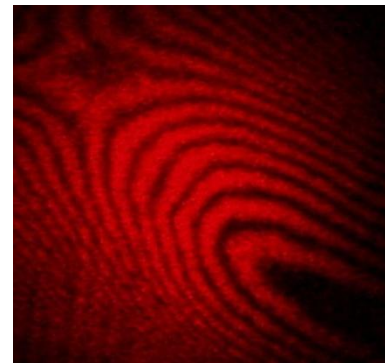
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# Light Bucket Mirrors I



- 7" pneumatic mirror
- Complex interferograms



# Light Bucket Mirrors II



- 12" pneumatic mirror
- Vega (w/no correction)



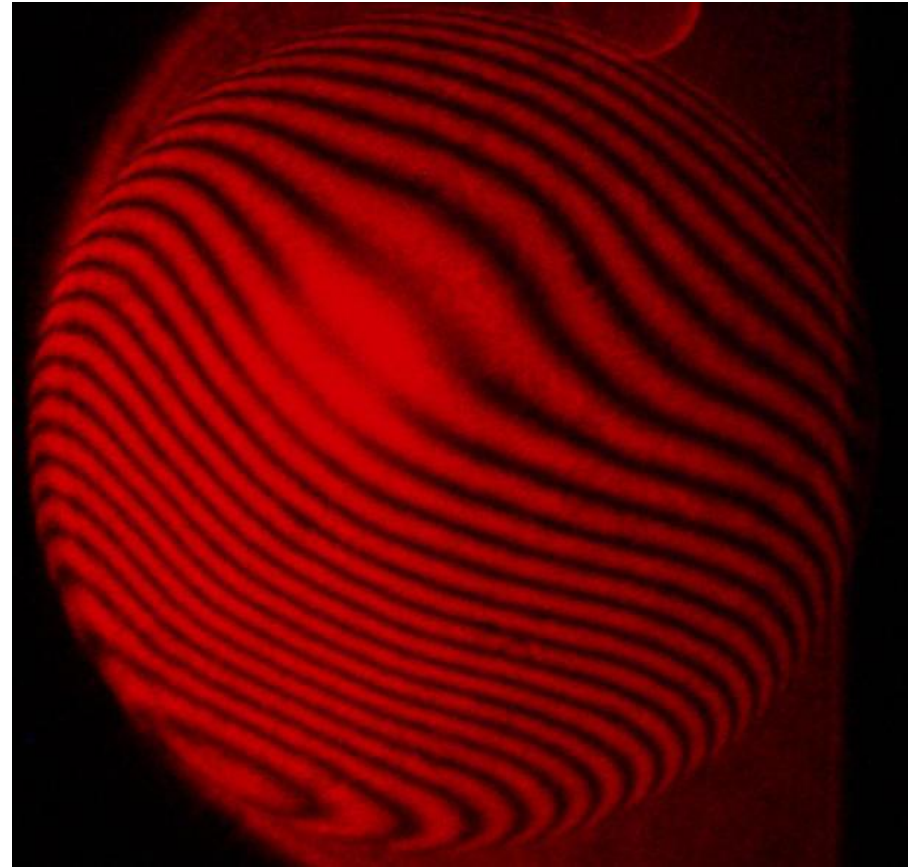


# Light Bucket Mirrors III

- Our first 1-meter light bucket...

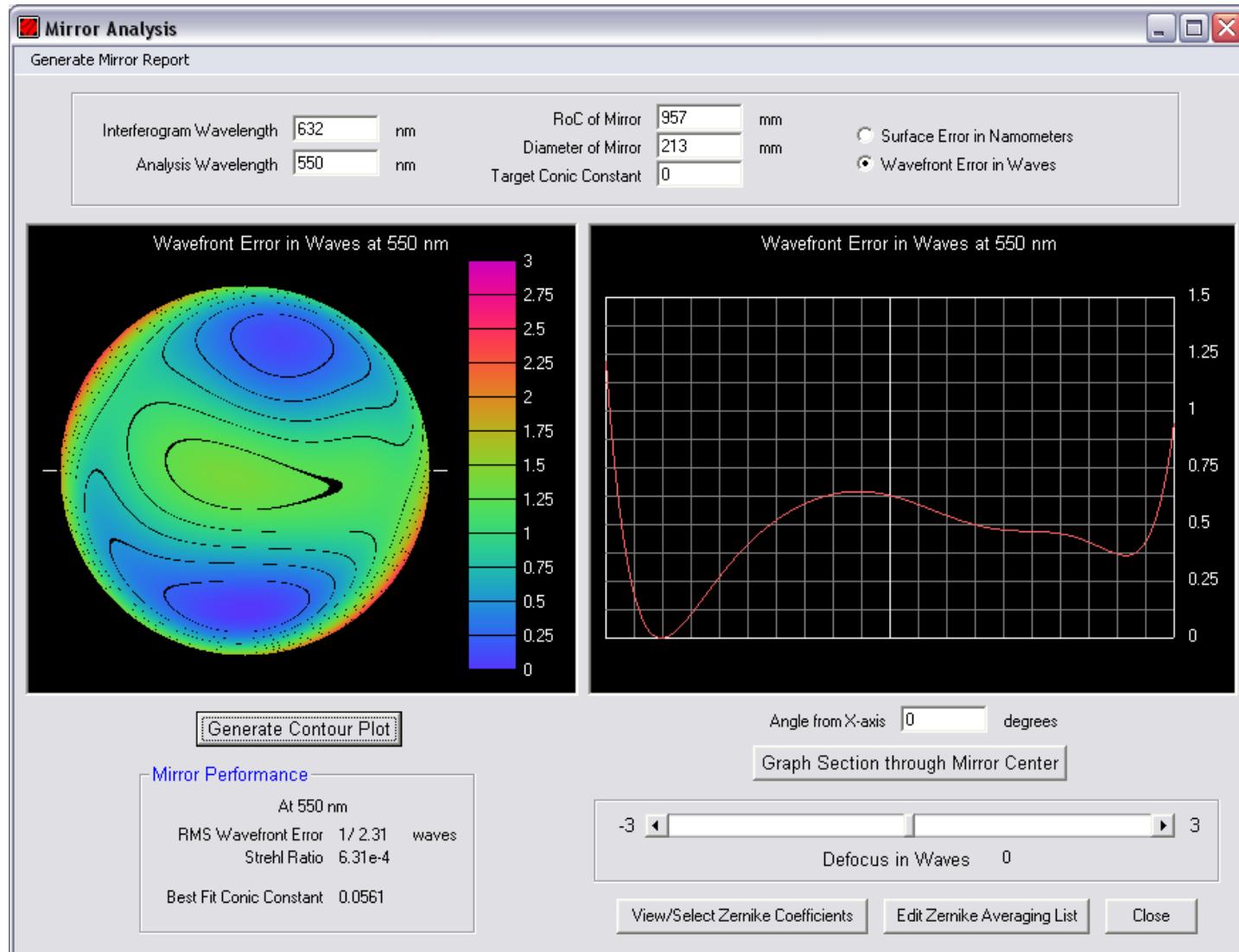


# Starstone evaluation I



- Mirror 0001A 8" f/2.25

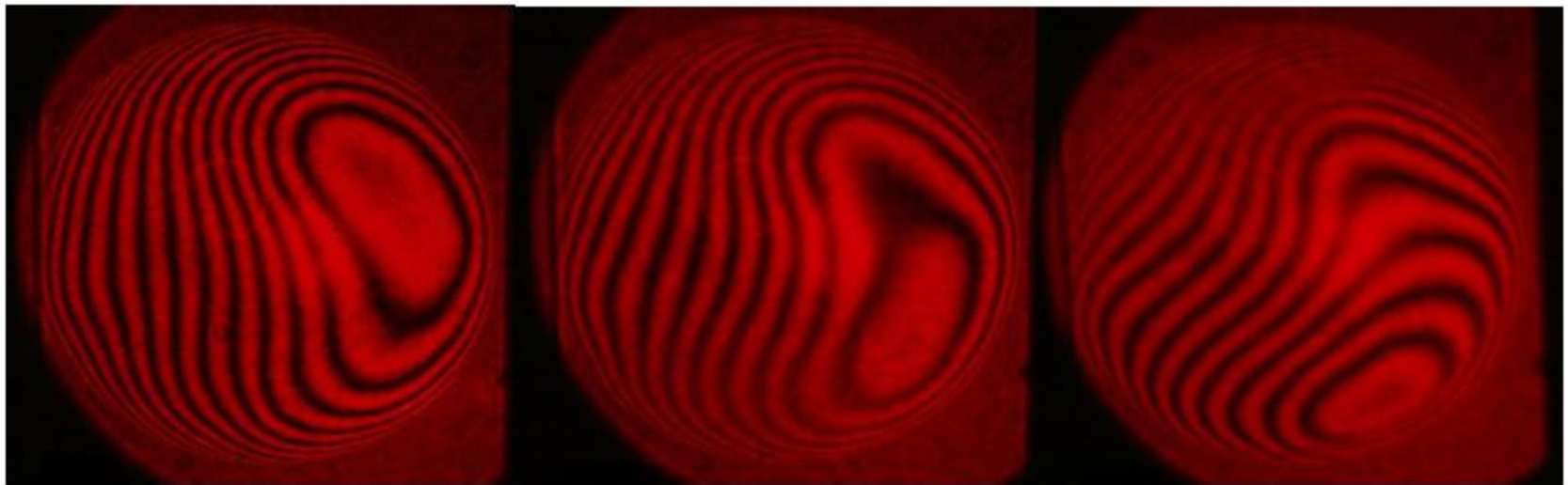
# Starstone evaluation II





# Starstone evaluation III

- Cooling after 30 sec. warming with heat gun



7:32:26pm

7:32:54pm

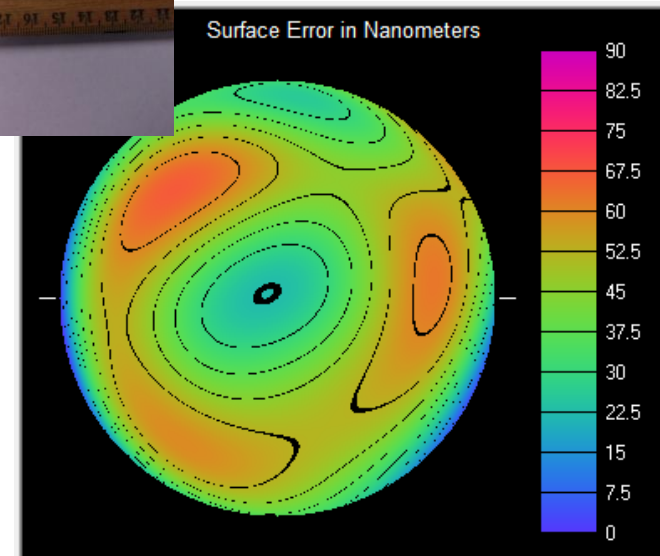
7:33:52pm

# Starstone evaluation IV

- Corrector used– 50-mm projection lens
- Hubble optics 5-star flashlight 50 to 250 micron  
“stars” @11-m
- 180" – no correction
- 25" – with correction



# Peacock Labs I



- Cold silvering processes
- Located in Philly
- 8 calibrated mirrors to be coated with their various products

Generate Contour Plot

## Mirror Performance

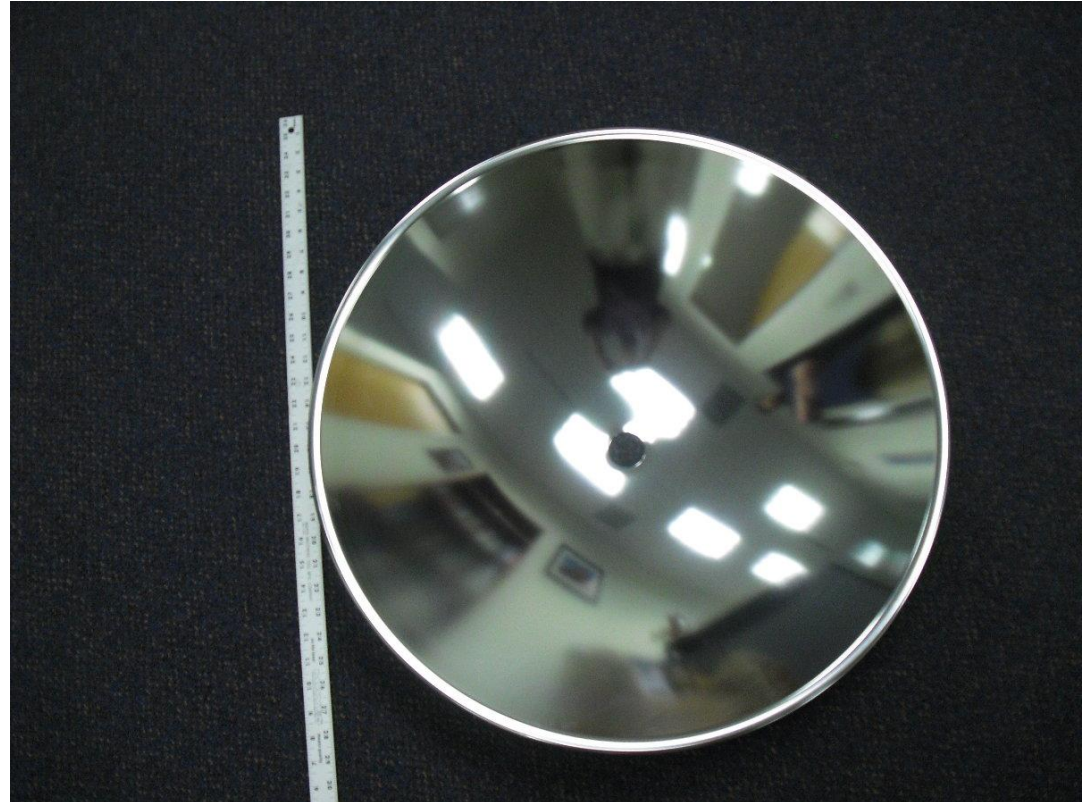
At 550 nm

RMS Wavefront Error 1/ 23.6 waves  
Strehl Ratio 0.931

Best Fit Conic Constant -0.698

# Other Potential LBT Mirrors

- Edmund 24" parabolic
- Aluminum 0.04"
- f/0.25
- 1.5" central hole
- Low reflectivity (not "precision polished")



# Correctors

- Spherical aberration:  $f/4$ ,  $f/2$ , even  $f/1$
- One & two spherical lens designs (off-the-shelf)
- Slumped meniscus
- Projection lenses with aspherics

# Dave Rowe's 1-m, f/4 Corrector

<input type="button" value="Optimize"/>		Curvature <input type="text" value="1e-5"/> SC <input type="text" value="0.001"/> Spacing <input type="text" value="0.2"/> Corrector <input type="text" value="0.002"/>	<input type="button" value="Trace"/>		Wavelengths (nm) Red <input type="text" value="750"/> Green <input type="text" value="550"/> Blue <input type="text" value="420"/>	FOV <input type="text" value="0.2"/>	<input type="button" value="Auto Scale"/>	1.02" per					
Statistics <a href="#">437/7281</a> Error <a href="#">19.116 um</a>		<input checked="" type="checkbox"/> Auto Focus Polychromatic	EFL <a href="#">4046.5</a> f/D <a href="#">4.047</a>		Off-axis Angle (deg) <input type="text" value="0"/> Off-axis Distance <input type="text" value="0"/> Trans (%) <a href="#">100</a> RMS Size <a href="#">4.004e-4</a> Optimizer Weight <input type="text" value="1"/>								
<b>0 Object</b> Distance <input type="text" value="1e20"/> Diameter <input type="text" value="1000"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt		<b>4 Focal Surface</b> Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt		<div style="border: 1px solid gray; padding: 5px;"> <b>Optical Layout</b> <div style="display: flex; justify-content: space-between; align-items: center;"> <span>Fit On Screen</span> <span> <input checked="" type="checkbox"/> Angle0           <input checked="" type="checkbox"/> Angle1           <input checked="" type="checkbox"/> Angle2         </span> <span>Rays 7</span> </div> </div>									
<b>1 Mirror</b> Radius <input type="text" value="7950"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="1000"/> Spacing <input type="text" value="3700"/> <input type="checkbox"/> Opt									Off-axis Angle (deg) <input type="text" value="0.05"/> Off-axis Distance <input type="text" value="3.546"/> Trans (%) <a href="#">100</a> RMS Size <a href="#">0.01993</a> Optimizer Weight <input type="text" value="1"/>				
<b>2 Lens BK7</b> Radius 1 <input type="text" value="-139.98"/> <input checked="" type="checkbox"/> Opt Thickness <input type="text" value="5"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="-228.803"/> <input checked="" type="checkbox"/> Opt Diameter <input type="text" value="75"/> Spacing <input type="text" value="1"/> <input type="checkbox"/> Opt									Off-axis Angle (deg) <input type="text" value="0.0715"/> Off-axis Distance <input type="text" value="5.068"/> Trans (%) <a href="#">97.79</a> RMS Size <a href="#">0.03702</a> Optimizer Weight <input type="text" value="1"/>				
<b>3 Lens BK7</b> Radius 1 <input type="text" value="80.2317"/> <input checked="" type="checkbox"/> Opt Thickness <input type="text" value="6"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="98.4438"/> <input checked="" type="checkbox"/> Opt Diameter <input type="text" value="75"/> Spacing <input type="text" value="269.833"/> <input type="checkbox"/> Opt													

# Tong Liu's f/4 design on f/2 8"

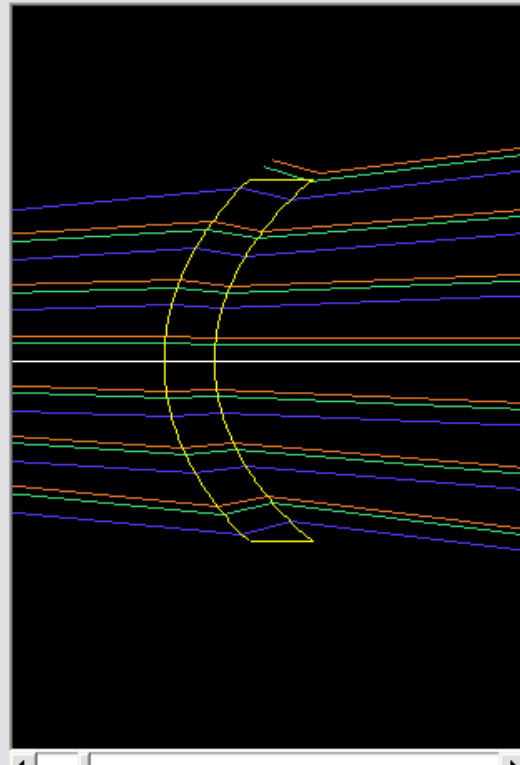
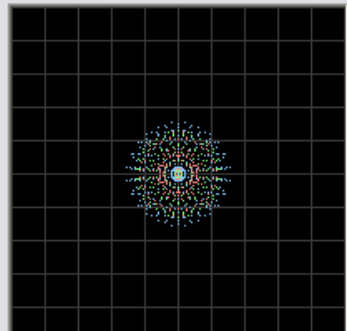
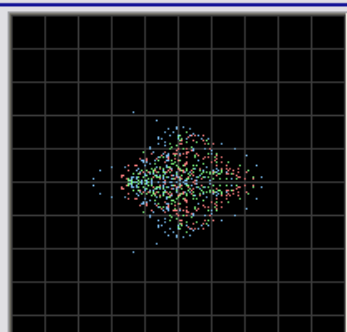
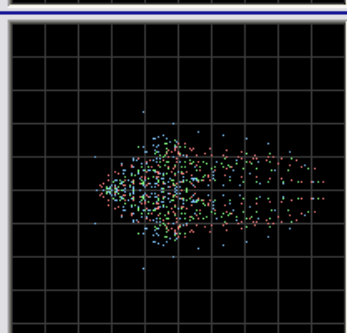
<input type="button" value="Optimize"/>		Curvature <input type="text" value="1e-6"/>	<input type="button" value="Trace"/>		EFL <input type="text" value="407.24"/>	Red <input type="text" value="750"/> nm	FOV <input type="text" value="0.15"/>	<input type="button" value="Auto Scale"/>	7.6" per
Stats <input type="text" value="1/351"/> Error <input type="text" value="19.494 um"/>		SC <input type="text" value="0.001"/>	<input type="checkbox"/> Auto Focus <b>Polychromatic</b>		f/D <input type="text" value="2.036"/>	Green <input type="text" value="550"/> nm			
		Spacing <input type="text" value="0.05"/>				Blue <input type="text" value="420"/> nm			
		Corrector <input type="text" value="0.002"/>							

<b>0 Object</b> Distance <input type="text" value="1e20"/> Diameter <input type="text" value="200"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt	<b>Optical Layout</b> <input type="button" value="Fit On Screen"/> <input checked="" type="checkbox"/> Angle0 <input checked="" type="checkbox"/> Angle1 <input checked="" type="checkbox"/> Angle2 <input type="text" value="10"/> Rays	Angle (deg) <input type="text" value="0"/> Distance <input type="text" value="0"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.02576"/> Weight <input type="text" value="0.7"/>	
<b>1 Mirror</b> Radius <input type="text" value="800"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="200"/> Spacing <input type="text" value="348.38"/> <input checked="" type="checkbox"/> Opt		Angle (deg) <input type="text" value="0.05"/> Distance <input type="text" value="0.3725"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.03893"/> Weight <input type="text" value="1"/>	
<b>2 Lens BK7</b> Radius 1 <input type="text" value="-64.6"/> <input type="checkbox"/> Opt Thickness <input type="text" value="5"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="1e20"/> <input type="checkbox"/> Opt Diameter <input type="text" value="50"/> Spacing <input type="text" value="0.5"/> <input type="checkbox"/> Opt		Angle (deg) <input type="text" value="0.07"/> Distance <input type="text" value="0.5214"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.04831"/> Weight <input type="text" value="1"/>	
<b>3 Lens BK7</b> Radius 1 <input type="text" value="64.6"/> <input type="checkbox"/> Opt Thickness <input type="text" value="10"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="1e20"/> <input type="checkbox"/> Opt Diameter <input type="text" value="50"/> Spacing <input type="text" value="43.683"/> <input checked="" type="checkbox"/> Opt		<b>4 Focal Surface</b> Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt	

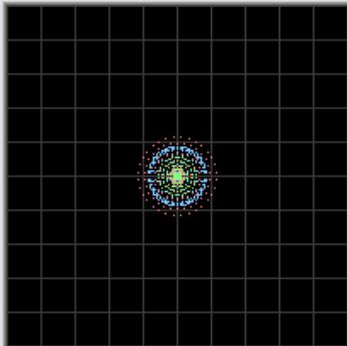
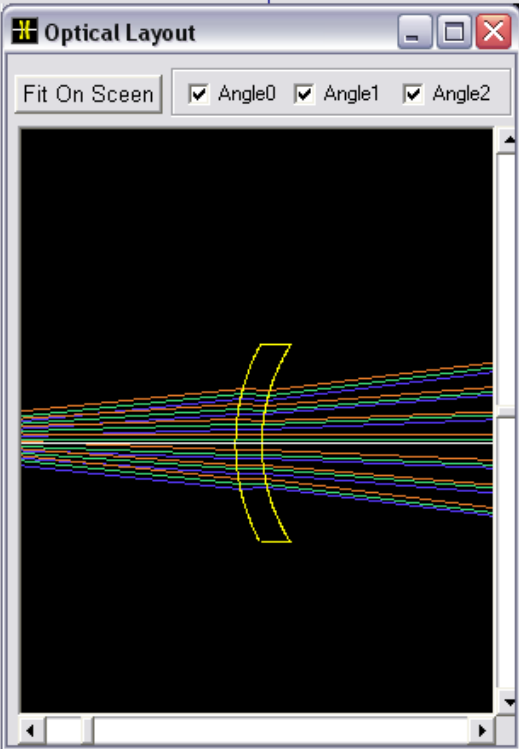
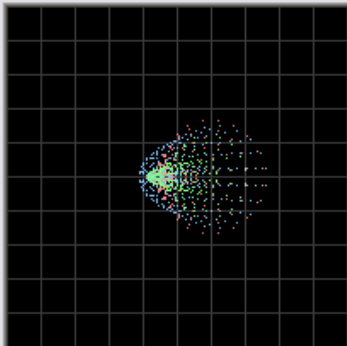
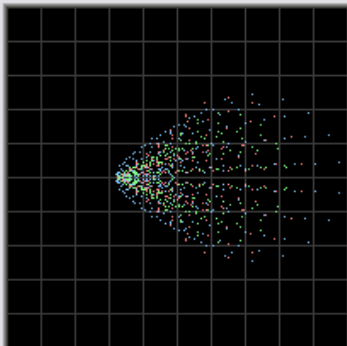


# 1-m f/4 BK4

Optimize	Curvature <input type="text" value="1e-6"/> SC <input type="text" value="0.001"/> Spacing <input type="text" value="0.05"/> Corrector <input type="text" value="0.002"/>	Trace <input type="checkbox"/> Auto Focus Polychromatic	EFL 5159.9  f/D 5.16	Red <input type="text" value="750"/> nm Green <input type="text" value="550"/> nm Blue <input type="text" value="420"/> nm	FOV <input type="text" value="0.2"/> Auto Scale 0.799" per
Stats 54/41486 Error 25.081 um					Angle (deg) <input type="text" value="0"/> Distance <input type="text" value="0"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.03611"/> Weight <input type="text" value="0.7"/>
<b>0 Object</b> Distance <input type="text" value="1e20"/> Diameter <input type="text" value="1000"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt	<div style="border: 1px solid black; padding: 5px;"> <b>Optical Layout</b>          Fit On Screen <input checked="" type="checkbox"/> Angle0 <input checked="" type="checkbox"/> Angle1 <input checked="" type="checkbox"/> Angle2 <input type="checkbox"/> Rays          </div>				
<b>1 Mirror</b> Radius <input type="text" value="7950"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="1000"/> Spacing <input type="text" value="3721.47"/> <input checked="" type="checkbox"/> Opt					
<b>2 Conic Lens BK7</b> Radius 1 <input type="text" value="-37.0143"/> <input checked="" type="checkbox"/> Opt SC 1 <input type="text" value="-0.715204"/> <input checked="" type="checkbox"/> Opt Thickness <input type="text" value="10.3015"/> <input checked="" type="checkbox"/> Opt Radius 2 <input type="text" value="-42.2732"/> <input checked="" type="checkbox"/> Opt SC 2 <input type="text" value="-0.666619"/> <input checked="" type="checkbox"/> Opt Diameter <input type="text" value="80"/> Spacing <input type="text" value="351.79"/> <input checked="" type="checkbox"/> Opt					
<b>3 Focal Surface</b> Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt					
					Angle (deg) <input type="text" value="0.05"/> Distance <input type="text" value="4.531"/> Trans (%) <input type="text" value="96.08"/> RMS Diam <input type="text" value="0.04475"/> Weight <input type="text" value="1"/>
					Angle (deg) <input type="text" value="0.07"/> Distance <input type="text" value="6.343"/> Trans (%) <input type="text" value="92.65"/> RMS Diam <input type="text" value="0.0654"/> Weight <input type="text" value="1"/>



# 1-m f/4 Plastic

<p>Optimize</p> <p>Statistics <b>0/122</b> Error <b>77.051 um</b></p>	<p>Curvature <input type="text" value="1e-5"/> SC <input type="text" value="0.001"/> Spacing <input type="text" value="0.2"/> Corrector <input type="text" value="0.002"/></p>	<p>Trace</p> <p><input type="checkbox"/> Auto Focus <b>Polychromatic</b></p>	<p>EFL <b>4706</b> f/D <b>4.706</b></p>	<p>Wavelengths (nm)</p> <p>Red <input type="text" value="656.3"/> Green <input type="text" value="587.6"/> Blue <input type="text" value="486.1"/></p>	<p>FOV <input type="text" value="1"/> Auto Scale 4.38" per </p> <p>Off-axis Angle (deg) <input type="text" value="0"/> Off-axis Distance <input type="text" value="0"/> Trans (%) <input type="text" value="100"/> RMS Size <b>0.06108</b> Optimizer Weight <input type="text" value="1"/></p> 
<p><b>0</b> Object</p> <p>Distance <input type="text" value="1e20"/> Diameter <input type="text" value="1000"/></p> <p>Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt</p>				<p>Off-axis Angle (deg) <input type="text" value="0.05"/> Off-axis Distance <input type="text" value="4.191"/> Trans (%) <input type="text" value="100"/> RMS Size <b>0.09321</b> Optimizer Weight <input type="text" value="0.5"/></p> 	
<p><b>1</b> Mirror</p> <p>Radius <input type="text" value="7950"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="1000"/></p> <p>Spacing <input type="text" value="3705.32"/> <input checked="" type="checkbox"/> Opt</p>				<p>Off-axis Angle (deg) <input type="text" value="0.1"/> Off-axis Distance <input type="text" value="8.385"/> Trans (%) <input type="text" value="100"/> RMS Size <b>0.156</b> Optimizer Weight <input type="text" value="0.1"/></p> 	
<p><b>2</b> Lens <b>PBH3</b></p> <p>Radius 1 <input type="text" value="-140"/> <input type="checkbox"/> Opt Thickness <input type="text" value="20"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="-160"/> <input type="checkbox"/> Opt Diameter <input type="text" value="150"/></p> <p>Spacing <input type="text" value="324.624"/> <input checked="" type="checkbox"/> Opt</p>					
<p><b>3</b> Focal Surface</p> <p>Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt</p>					

# 1-m f/2 Plastic

<input type="button" value="Optimize"/> Statistics <b>170/558</b> Error <b>101.94 um</b>	Curvature <input type="text" value="1e-5"/> SC <input type="text" value="0.001"/> Spacing <input type="text" value="0.2"/> Corrector <input type="text" value="0.002"/>	<input type="button" value="Trace"/> <input checked="" type="checkbox"/> Auto Focus <b>Polychromatic</b>	EFL <b>2435</b> f/D <b>2.435</b>	Wavelengths (nm) Red <input type="text" value="656.3"/> Green <input type="text" value="587.6"/> Blue <input type="text" value="486.1"/>	FOV <input type="text" value="1.5"/> <input type="button" value="Auto Scale"/> 12.7" per
<b>0</b> Object Distance <input type="text" value="1e20"/> Diameter <input type="text" value="1000"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt	<div style="border: 1px solid gray; padding: 5px;"> <b>Optical Layout</b>  <input type="button" value="Fit On Screen"/> <input checked="" type="checkbox"/> Angle0 <input checked="" type="checkbox"/> Angle1 <input checked="" type="checkbox"/> Angle2    Rays <input type="text" value="7"/> <input type="button" value="Repl"/> </div>			Off-axis Angle (deg) <input type="text" value="0"/> Off-axis Distance <input type="text" value="0"/> Trans (%) <input type="text" value="100"/> RMS Size <b>0.1019</b> Optimizer Weight <input type="text" value="1"/>	
<b>1</b> Mirror Radius <input type="text" value="4000"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="1000"/> Spacing <input type="text" value="1827.17"/> <input checked="" type="checkbox"/> Opt				Off-axis Angle (deg) <input type="text" value="0.05"/> Off-axis Distance <input type="text" value="2.269"/> Trans (%) <input type="text" value="100"/> RMS Size <b>0.1646</b> Optimizer Weight <input type="text" value="0"/>	
<b>2</b> Lens <span style="color: green;">PBH3</span> Radius 1 <input type="text" value="-120"/> <input type="checkbox"/> Opt Thickness <input type="text" value="25"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="-145"/> <input type="checkbox"/> Opt Diameter <input type="text" value="150"/> Spacing <input type="text" value="211.248"/> <input checked="" type="checkbox"/> Opt				Off-axis Angle (deg) <input type="text" value="0.1"/> Off-axis Distance <input type="text" value="4.539"/> Trans (%) <input type="text" value="100"/> RMS Size <b>0.2788</b> Optimizer Weight <input type="text" value="0"/>	
<b>3</b> Focal Surface Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt					

# 1-m f/4 Meniscus

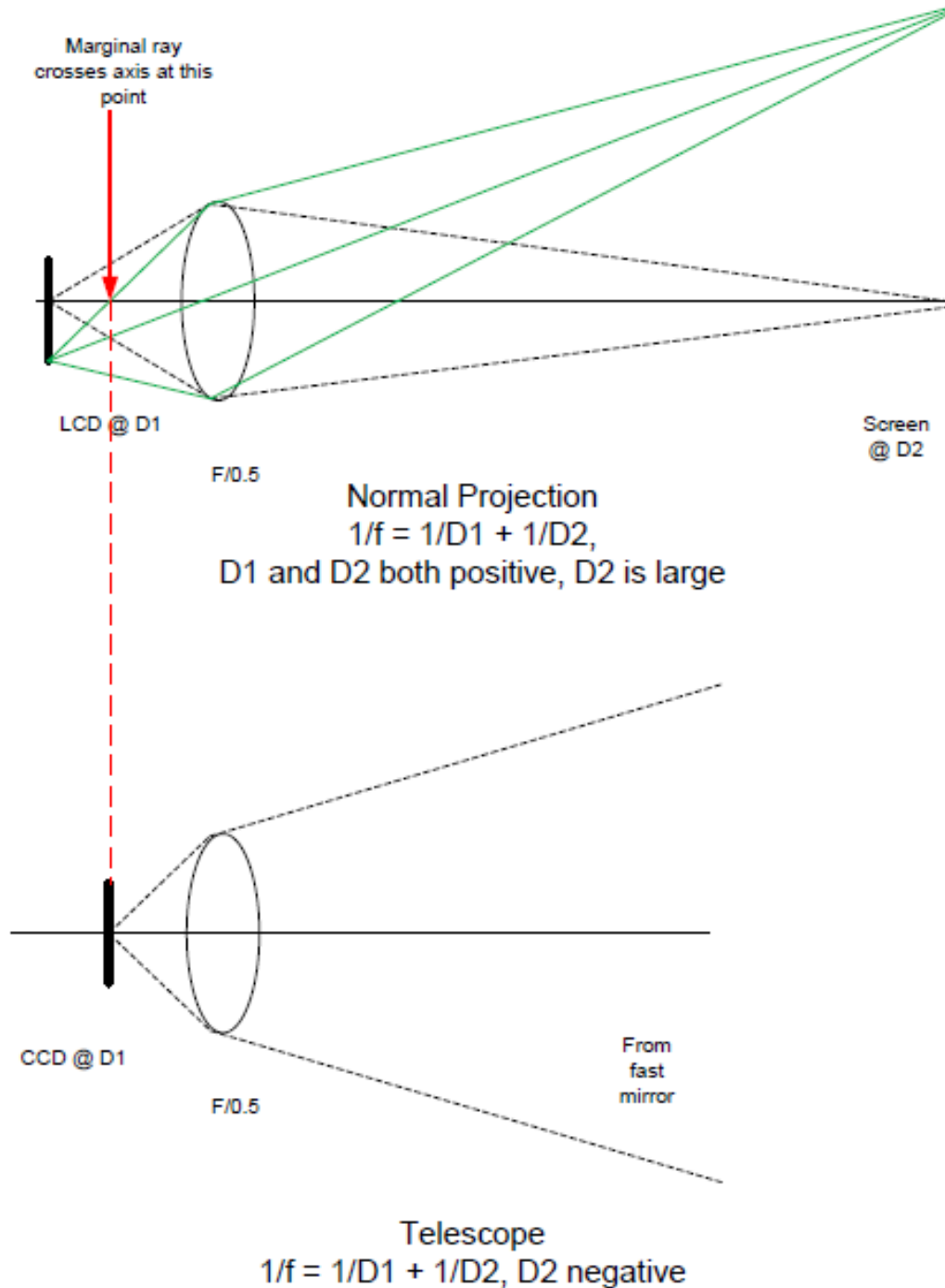
Optimize	Curvature <input type="text" value="1e-5"/> SC <input type="text" value="0.001"/>	Trace	EFL <input type="text" value="3964.5"/>	Red <input type="text" value="750"/> nm	FOV <input type="text" value="1"/> Auto Scale 5.2" per
Stats <input type="text" value="118/2049"/> Error <input type="text" value="56.47 um"/>	Spacing <input type="text" value="0.2"/> Corrector <input type="text" value="0.002"/>	<input type="checkbox"/> Auto Focus Polychromatic	f/D <input type="text" value="3.964"/>	Green <input type="text" value="550"/> nm Blue <input type="text" value="420"/> nm	

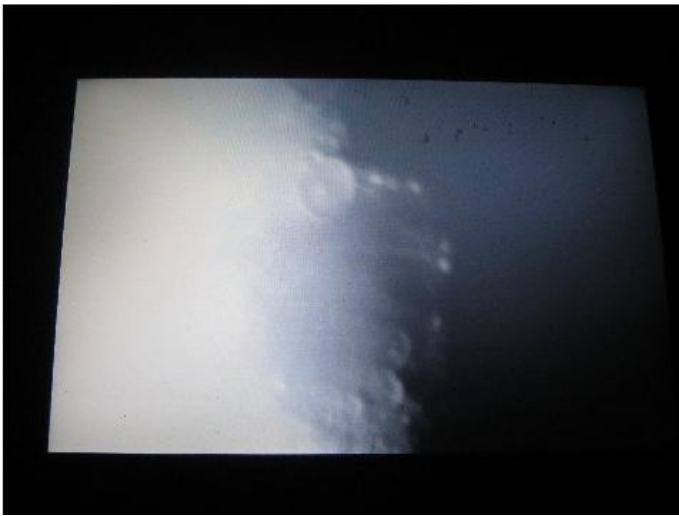
<b>0 Object</b> Distance <input type="text" value="1e20"/> Diameter <input type="text" value="1000"/> Spacing <input type="text" value="0"/> <input type="checkbox"/> Opt		Angle (deg) <input type="text" value="0"/> Distance <input type="text" value="0"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.02886"/> Weight <input type="text" value="1"/>
<b>1 Mirror</b> Radius <input type="text" value="7950"/> <input type="checkbox"/> Opt SC <input type="text" value="0"/> <input type="checkbox"/> Opt Diameter <input type="text" value="1000"/> Spacing <input type="text" value="3646.03"/> <input checked="" type="checkbox"/> Opt		Angle (deg) <input type="text" value="0.05"/> Distance <input type="text" value="3.525"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.1278"/> Weight <input type="text" value="1"/>
<b>2 Lens BK7</b> Radius 1 <input type="text" value="-90"/> <input type="checkbox"/> Opt Thickness <input type="text" value="2.3"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="-92.3"/> <input type="checkbox"/> Opt Diameter <input type="text" value="100"/> Spacing <input type="text" value="1"/> <input type="checkbox"/> Opt		Angle (deg) <input type="text" value="0.0715"/> Distance <input type="text" value="5.042"/> Trans (%) <input type="text" value="100"/> RMS Diam <input type="text" value="0.1822"/> Weight <input type="text" value="1"/>
<b>3 Lens BK7</b> Radius 1 <input type="text" value="120"/> <input type="checkbox"/> Opt Thickness <input type="text" value="2.3"/> <input type="checkbox"/> Opt Radius 2 <input type="text" value="122.3"/> <input type="checkbox"/> Opt Diameter <input type="text" value="100"/> Spacing <input type="text" value="324.128"/> <input checked="" type="checkbox"/> Opt		
<b>4 Focal Surface</b> Radius <input type="text" value="1e20"/> <input type="checkbox"/> Opt		

# Aspherics

- Olive3 is out-of-date
- Projection lenses
  - Movie
  - LCD  $\sim f/2$
  - Rear Proj. TV  $\sim f/1$



# Gaussian Kernel I

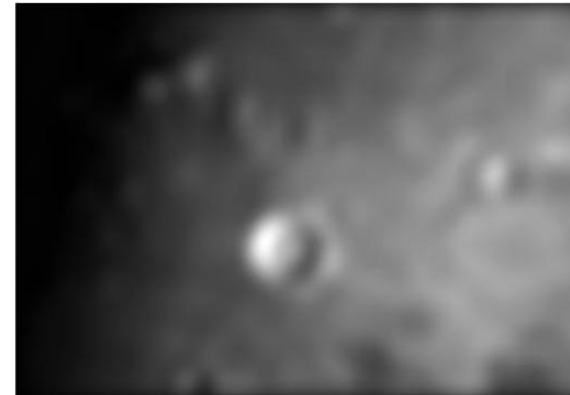


Above : Russ's 1-m  
f/4 w/no  
correction

Moon image from  
web



50x50 Gaussian  
Kernel applied to  
approximate f/4



With 4x reduction  
expected from  
Tong Liu's  
corrector design



# Gaussian Kernel II



- Albirio pair – 35" apart
- Middle and right images correspond to the lunar ones on the previous slide.

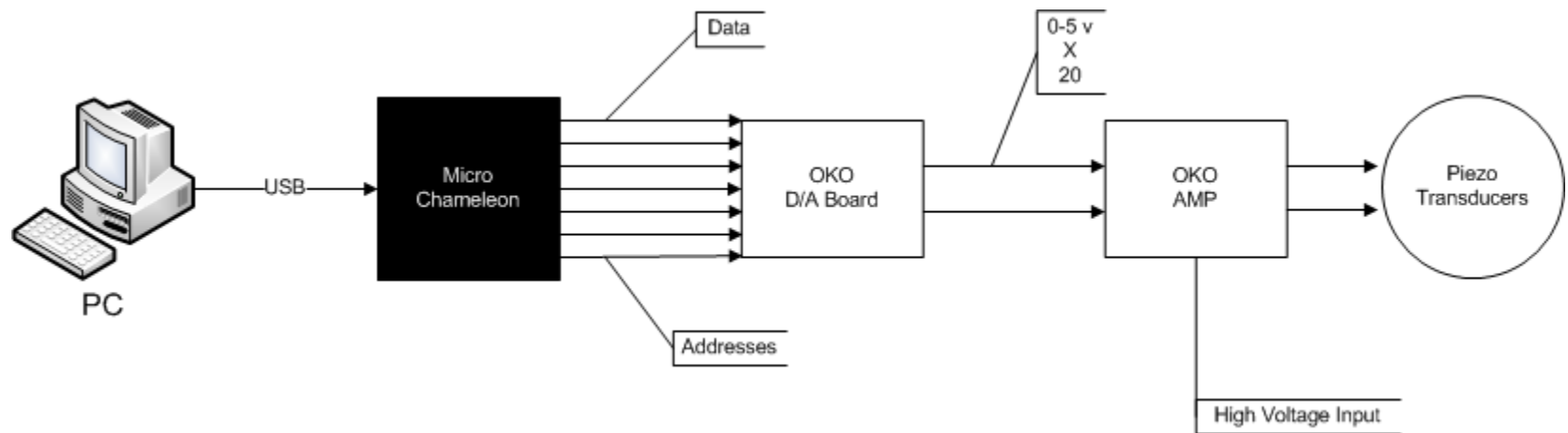
# Deformable Mirrors I

- Goals
  - Active, not adaptive, correction for LBTs
  - Low-cost & replicable
  - Explore relationship between prediction and experiment
- Current State
  - Deformable Newtonian secondary  $45^\circ$
  - 40 actuators



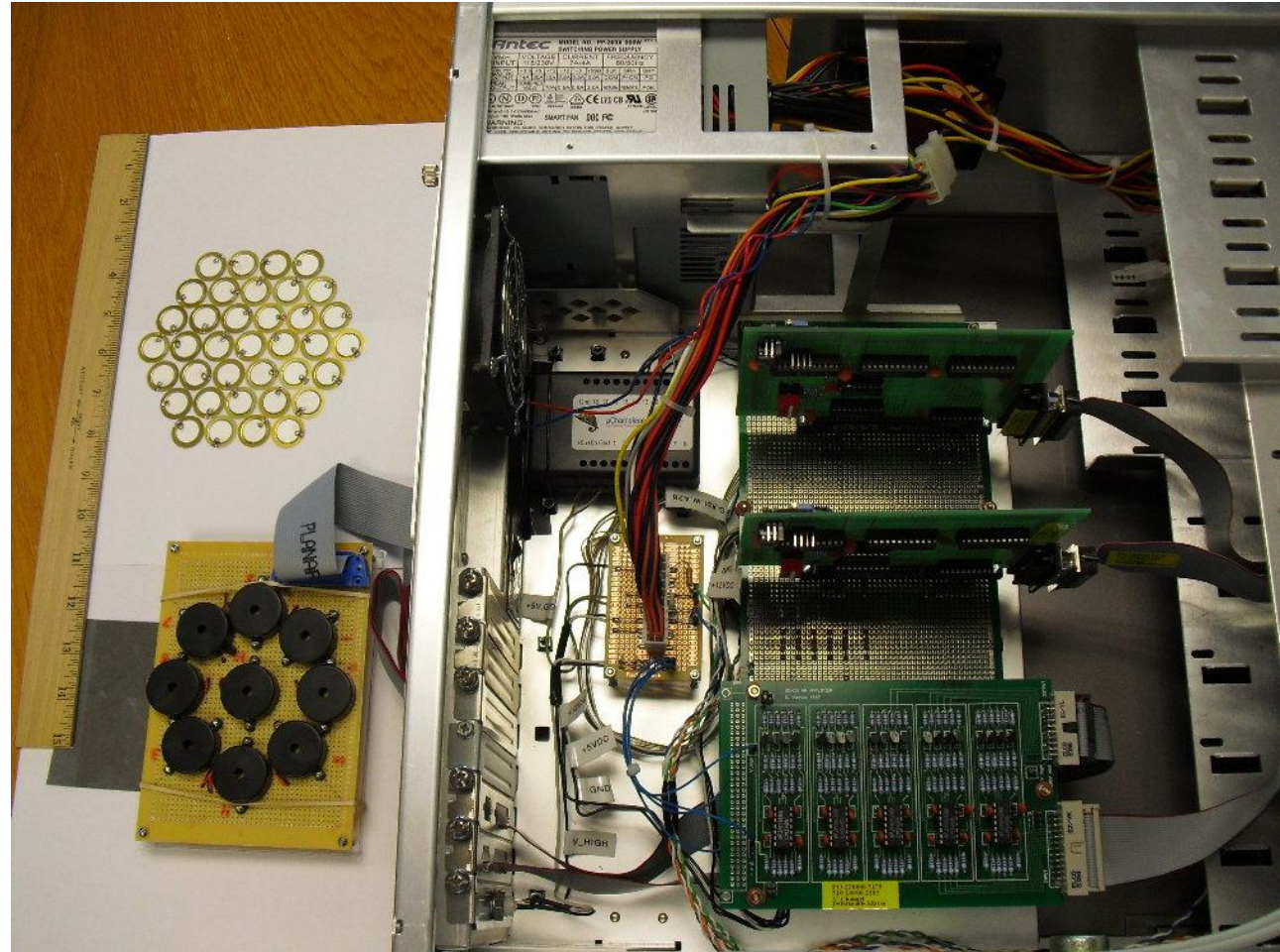
# Deformable Mirrors II

- Controller



# Deformable Mirrors III

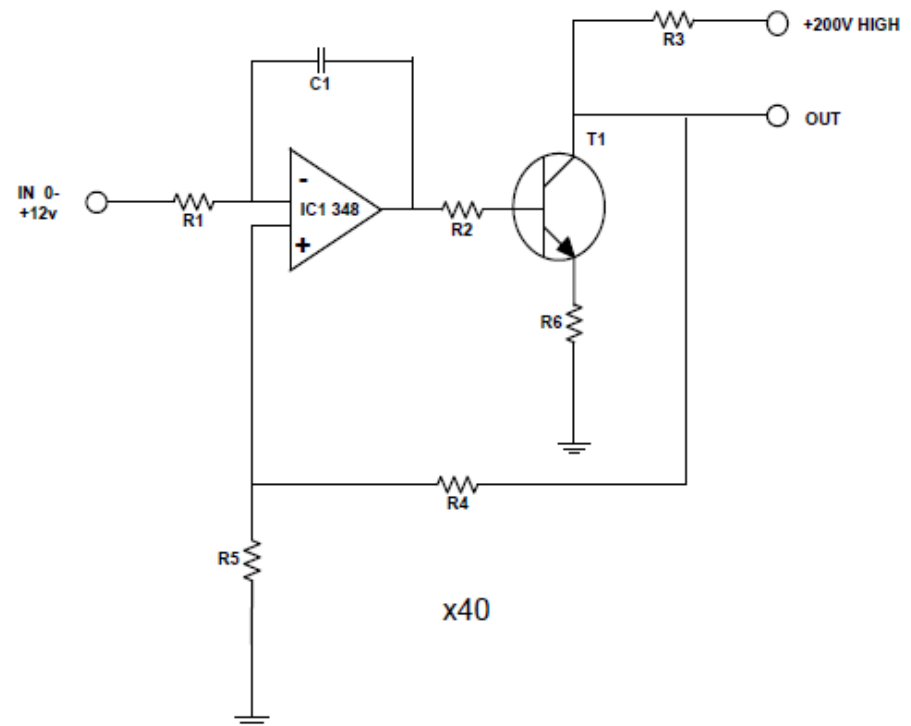
- Re-used old ISA OKO boards
- USB
- $\mu$ Chameleon
- 500Hz update rate
- 40-channel
- 0-200V Out



# Deformable Mirrors IV

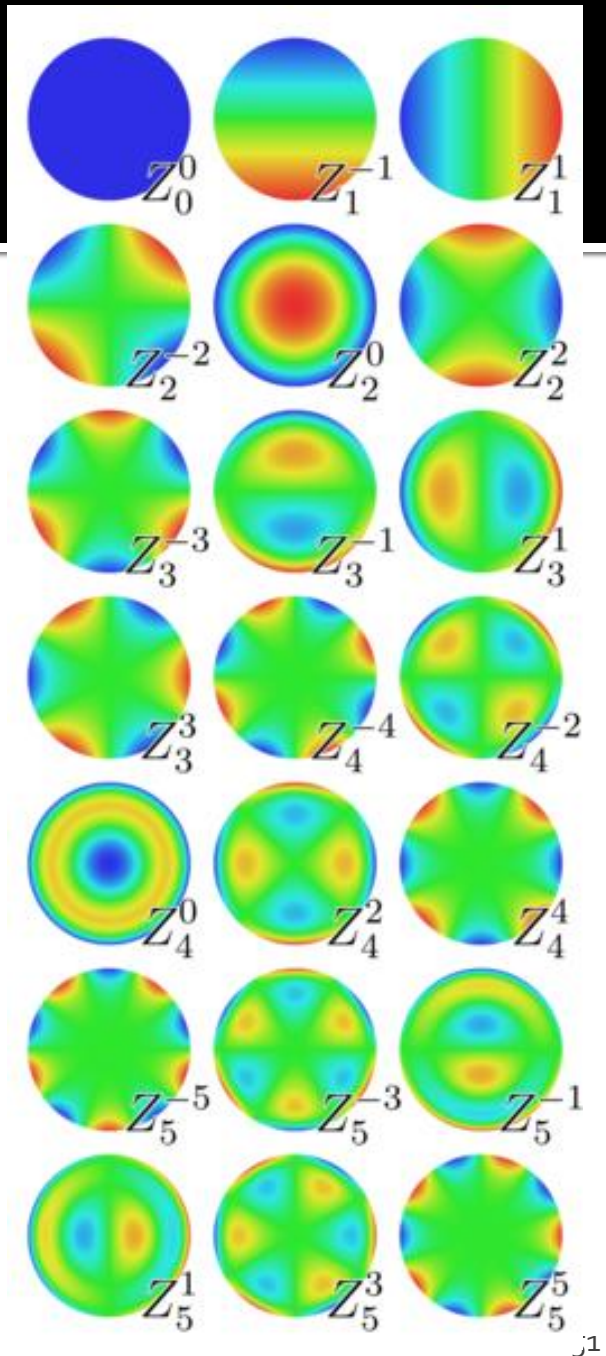
- HV amp: 0-3v in, 0-200v out
- 500Hz update rate
- MPSA42 @ \$0.05ea.  
Qty. 2k

R1, 47k 1%  
R2, 2.7k 1%  
R3, 270k 1%  
R4, 2.7M 1%  
R5, 47k 1%  
R6, 47 1%  
C1, 151k Pf  
T1, MPSA42 NPN (300v)  
IC1, LM348



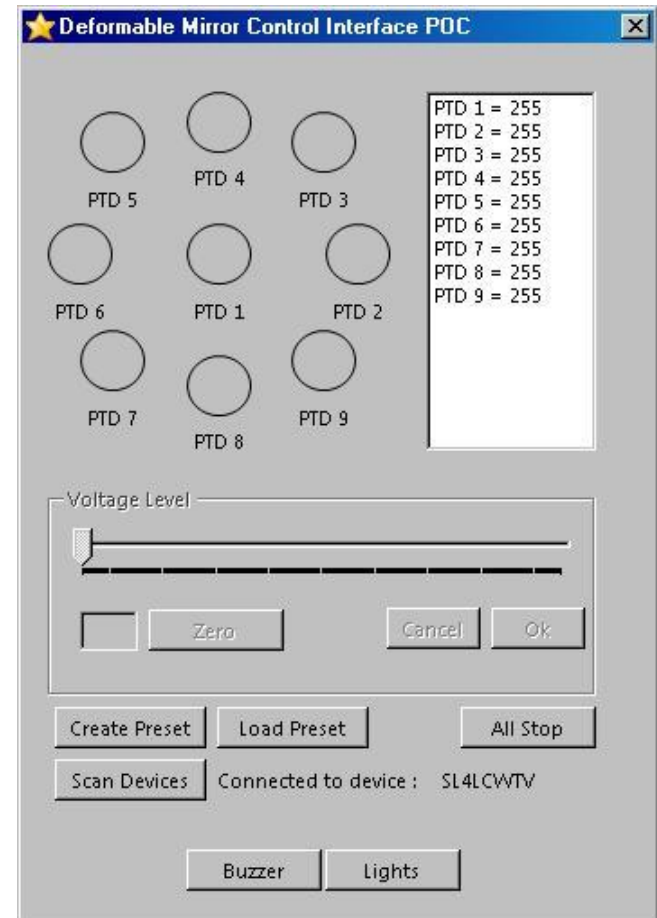
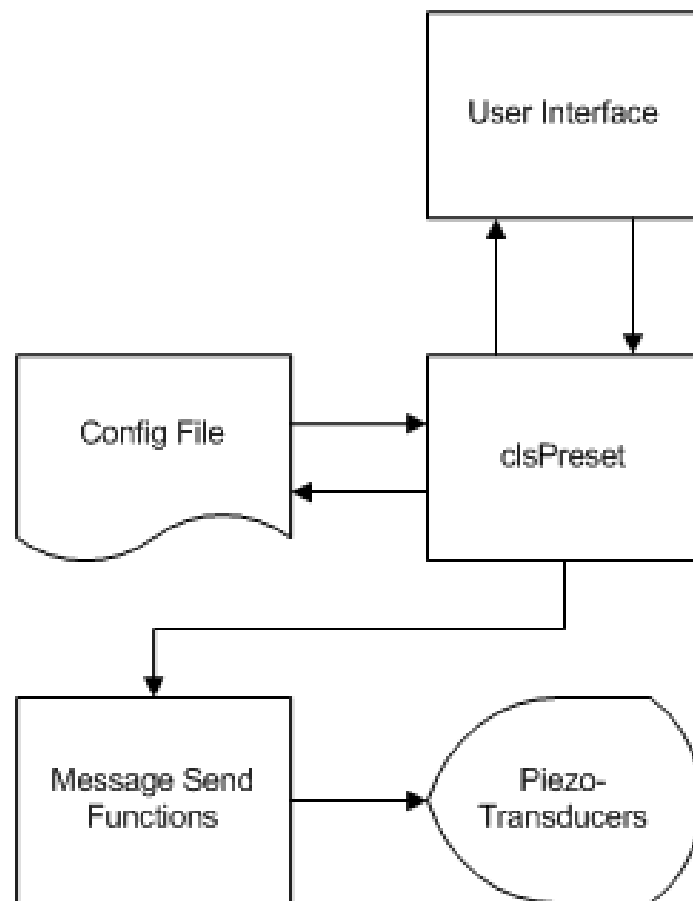
# Deformable Mirrors V

- Zernike orthonormal functions
- Closed loop
  - Wavefront sampling
  - Active correction
- Open loop
  - Minimize PSF (simulated annealing)
  - Lookup table



# Deformable Mirrors VI

## ■ Control Software



# Topics

- Research Opportunities
  - Occultations & other topics
- Light Bucket Astronomy
  - Light bucket theory
  - Relative SNRs
- Optical Technologies
  - Light bucket mirrors
  - Correctors
  - Evaluations of other new technologies
- Instrumentation
  - Area and diaphragm detectors

# Fast Detectors

- Requirements
  - Low noise, high sensitivity
  - 300Hz BW & up
  - Affordable/replicable
- Fast Area
  - CCD & CMOS
  - Binning/Region of interest processing
  - GigE interface
- Fast diaphragm-limiting photometry
  - Silicone, InGaAs , PMT
- High Time Resolution Astronomy (future)



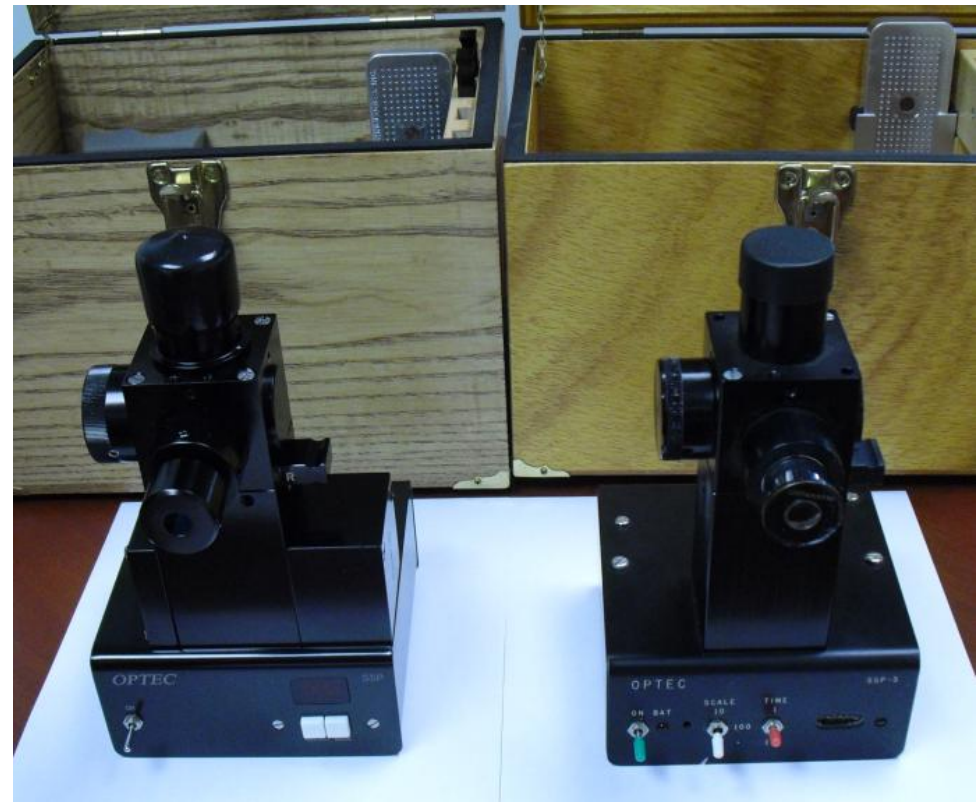
# Detectors – Fast Area

- Brand/products
  - SuperCircuits 164CEX-2 (CCD)
  - Opticstar PL-131 (CMOS)
  - JAI/Pulnix TM-6740GE (Kodak KAI-0340 CCD, GigE)
  - Many others: Cook Corp, MallinCam, Vision Research, Point Grey, Dalsa, Optronics, Xenics, Allied Vision Tech, Photon Focus, Qimaging, DRS Data & Imaging, Imperex, Prosilica, Watec (Wat-902H2 Ultimate), Lumenera (SKYnyx2-2), Astrovid (Stellacam)



# Diaphragm-limiting

- Current state
  - 5kHz BW transimpedance amplifier
  - Visible (Si) Diodes (IRD UVG100, Optec SSP-3)
  - Visible (PMT) (Optec SSP-5A)
  - Port of FCO PBPHOT software underway



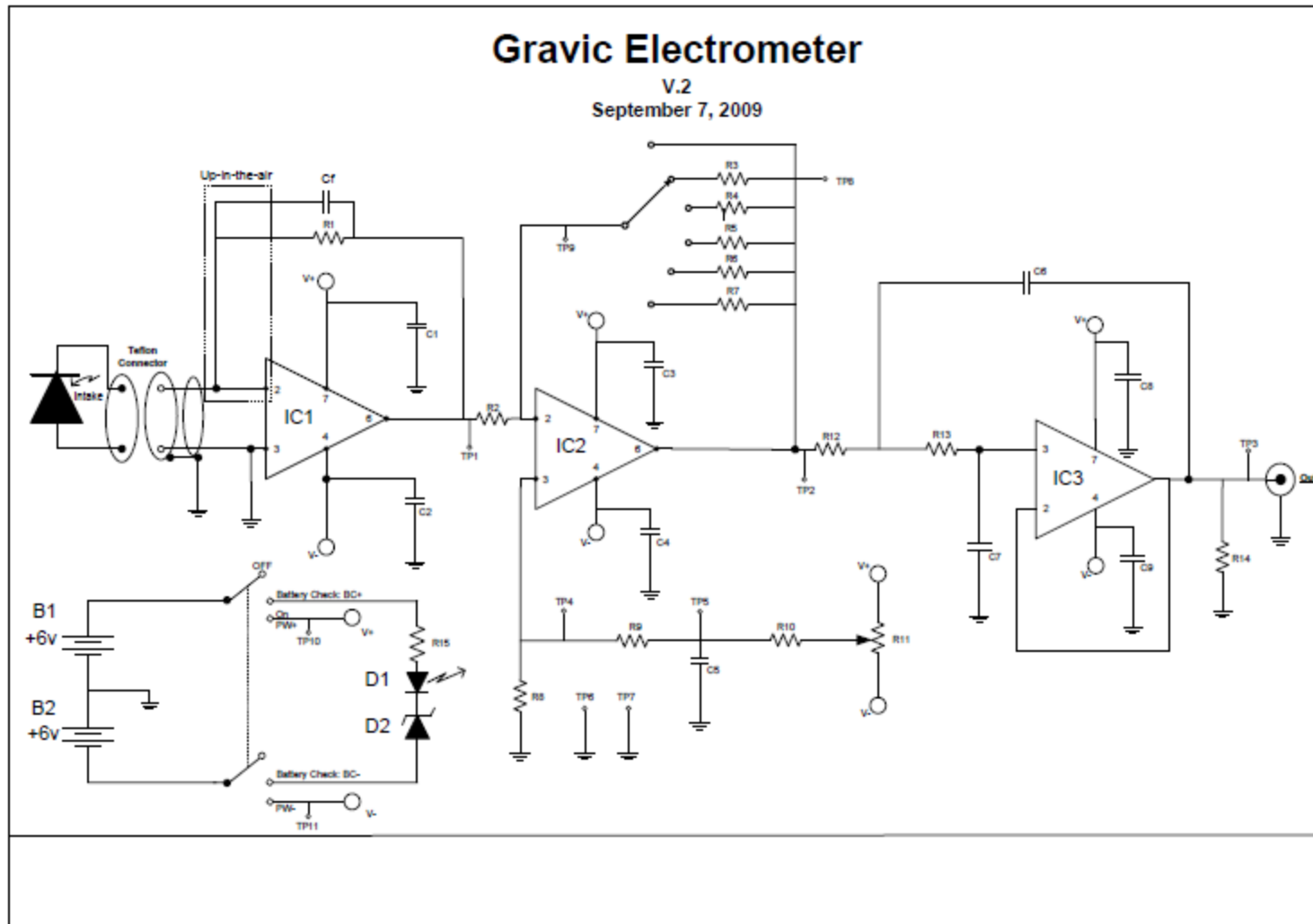
# High Speed Electrometer I





# High-Speed Electrometer II

- IRD detector
- 5kHz BW
- Also added overload circuit



# Electrometer parts

- R<sub>1</sub> – has to be modest to maintain BW

## PARTS LIST

<u>Resistor</u>	<u>Value (ohms)</u>	<u>Capacitor</u>	<u>Value (Farads)</u>	<u>Op Amp</u>	<u>Value</u>	<u>Battery</u>	<u>Value (volts)</u>	<u>Diode</u>	<u>Value</u>
R1	5G, 1%	C1	.1u	IC1	LMC6081	B1	6	D1	LED - 10mA
R2	5k, 1%	C2	.1u	IC2	OPA621	B2	6	D2	ZENER - 9v
R3	5k, 1%	C3	.1u	IC3	OPA621				
R4	50k, 1%	C4	.1u						
R5	500k, 1%	C5	.1u						
R6	5M, 1%	C6	3u						
R7	50M, 1%	C7	3u						
R8	100, 5%	C8	.1u						
R9	50k, 5%	C9	.1u						
R10	50k, 5%	Cf	R1/Detector specific-see LMC6081 spec.						
R11	100K, 5%								
R12	10k, 5%								
R13	10k, 5%								
R14	50, 5%								
R15	300, 1%								

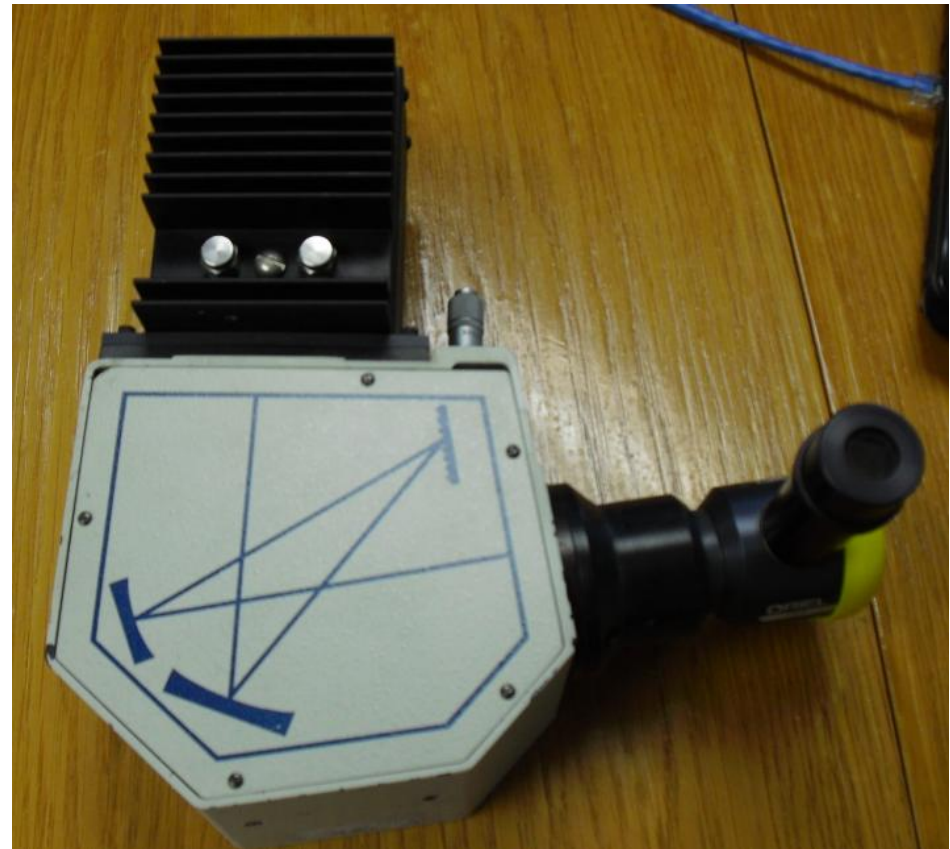
# Future HTRA experiments

- Three 12-cell Hamamatsu R1463P PMTs
- LeCroy 6100A samples at 10GS/s
- NVIDIA CUDA GPU for photon correlation



# Future experiments

- Oriel M125 Spectrograph (1/8 m)





# Contact & More Information

Bruce D. Holenstein

bholenstein@gravic.com

More details see:

2010 *Lightweight Alt-Az Telescope Developments*, ed. R. Genet,  
(Payson, AZ: Collins Foundation Press)

2011 (scheduled) *Light Bucket Astronomy*