Gravic Light Bucket Astronomy Projects 2010

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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

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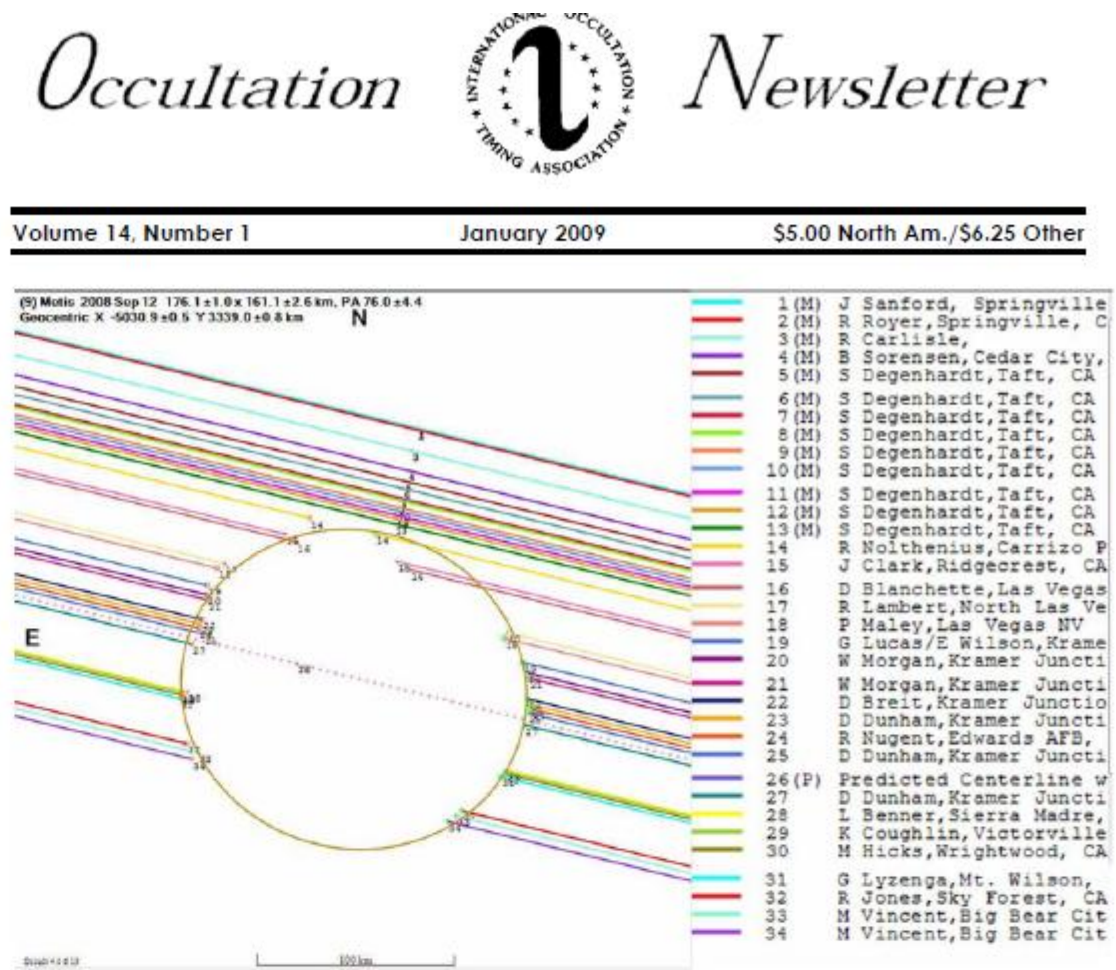
Research Opportunities

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

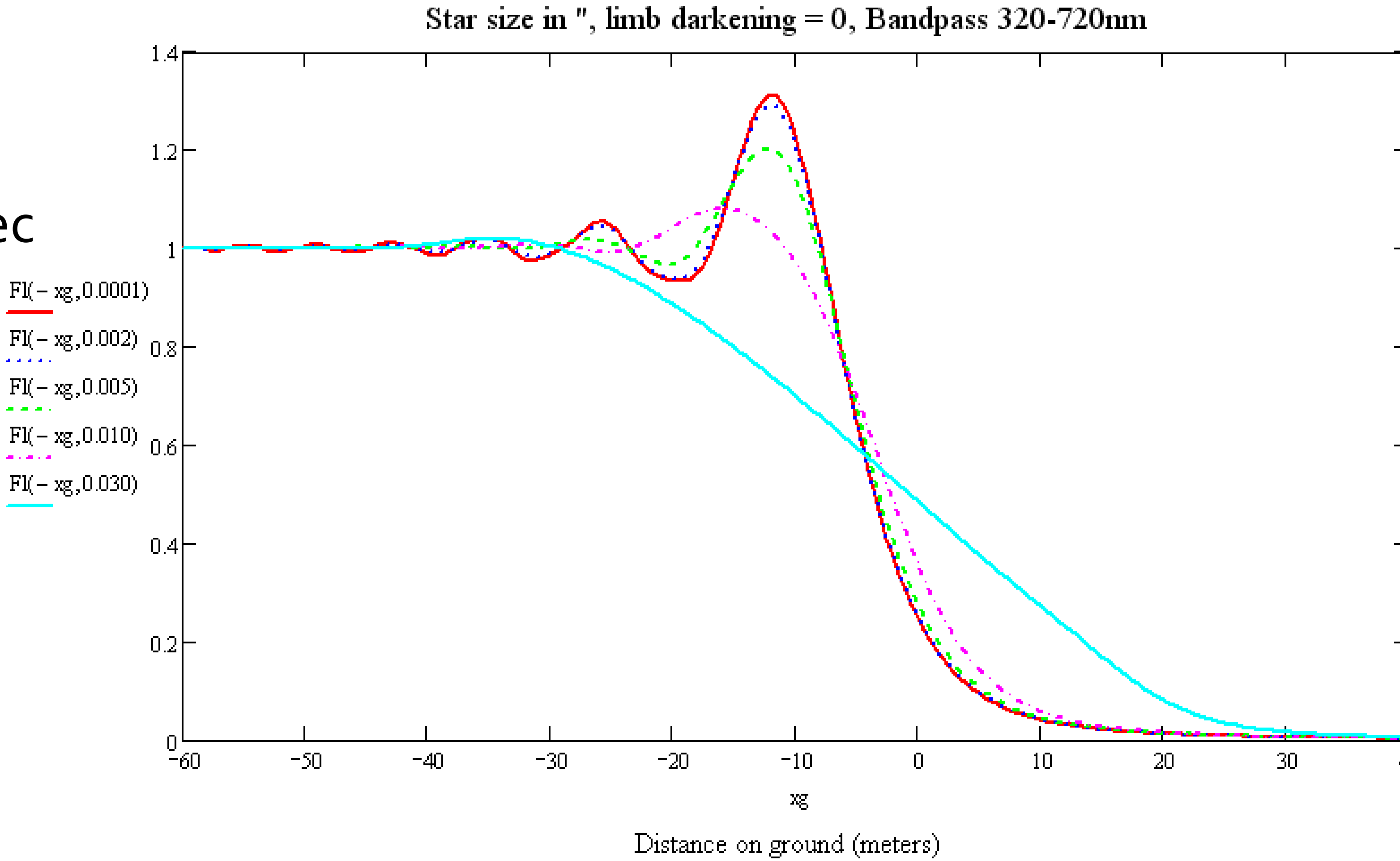
Occultations

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

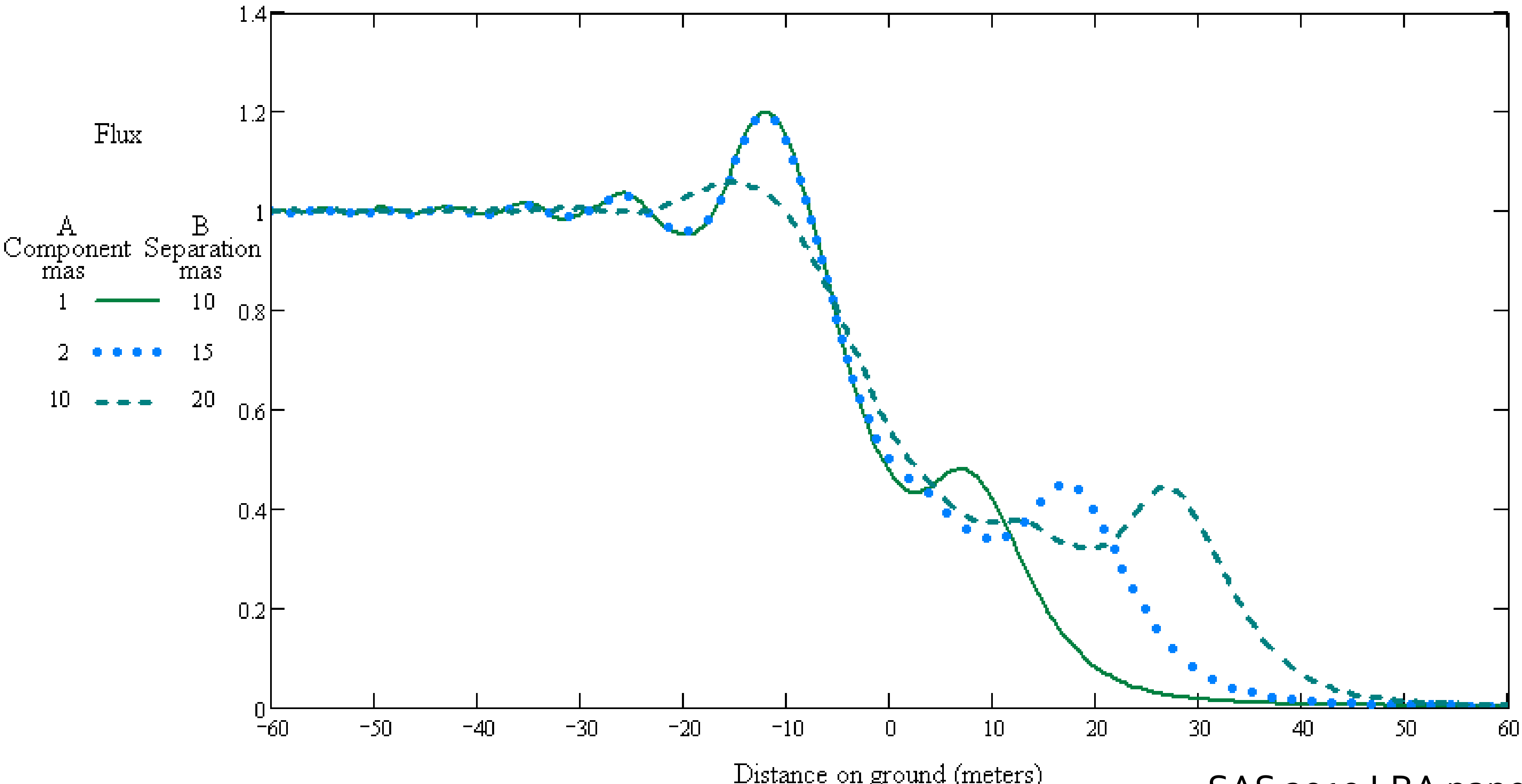


Lunar Occultations

- Single Star
- Moon ~0.3"/sec



Lunar Occultations II

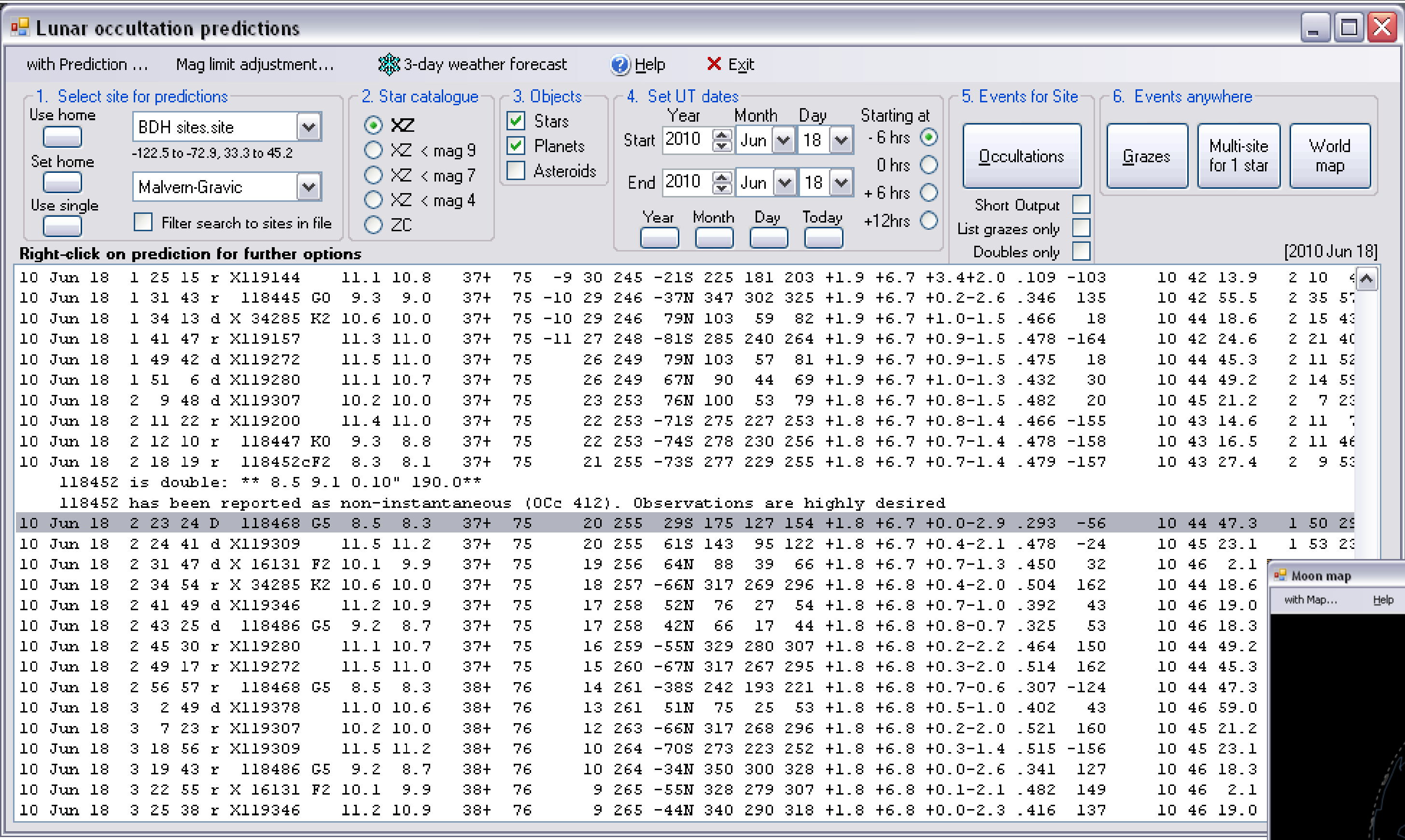


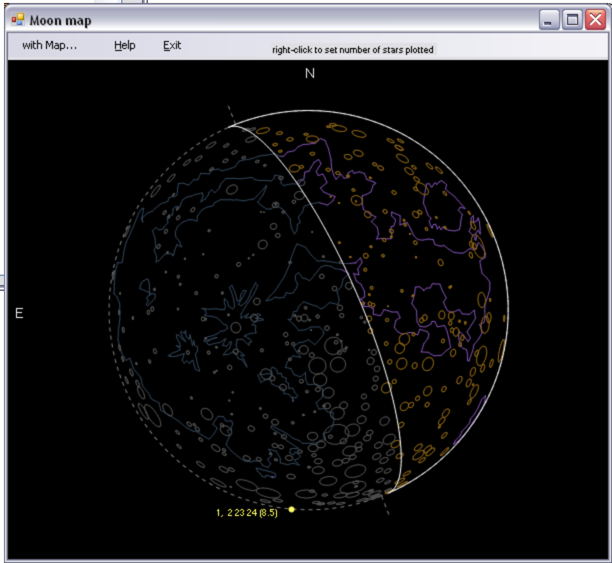
SAS 2010 LBA paper

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



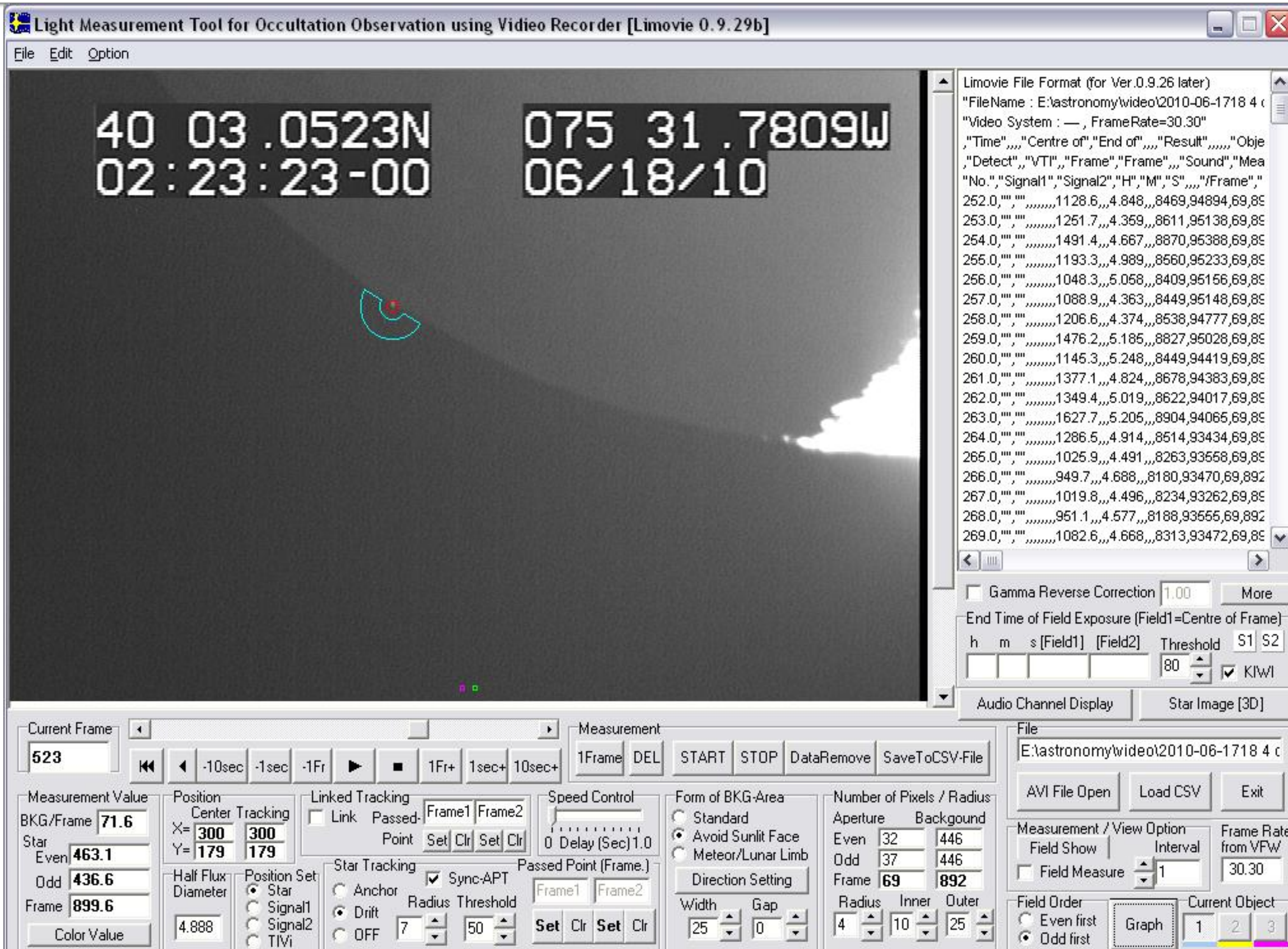


- Predictions based on location and elevation

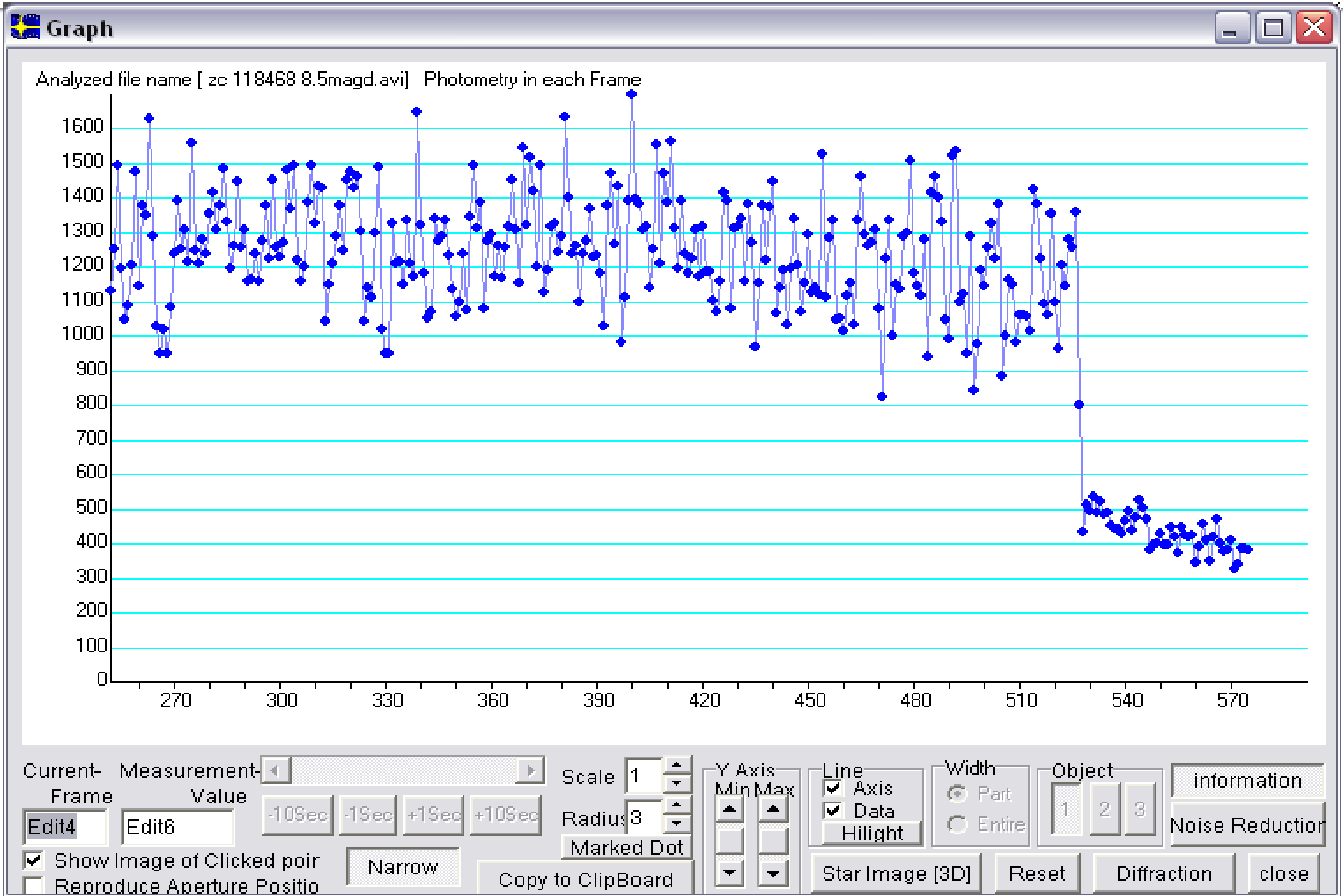
Video Equipment

N18 on IPI 393 GEM

Occultation Video



Light Curve



Graph
Analyzed file name [zc 118468 8.5magd.avi] Photometry in each Frame
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
270
300
330
360
390
420
450
480
510
540
570
Current-Frame
Measurement-Value
Edit4
Edit6
-10Sec
-1Sec
+1Sec
+10Sec
Scale 1
Radius 3
Marked Dot
Y Axis Min Max
Line
Axis
Data
Hilight
Width
Part
Entire
Object
1
2
3
information
Noise Reduction
Show Image of Clicked poir
Reproduce Aperture Positio
Narrow
Copy to ClipBoard
Star Image [3D]
Reset
Diffraction
close

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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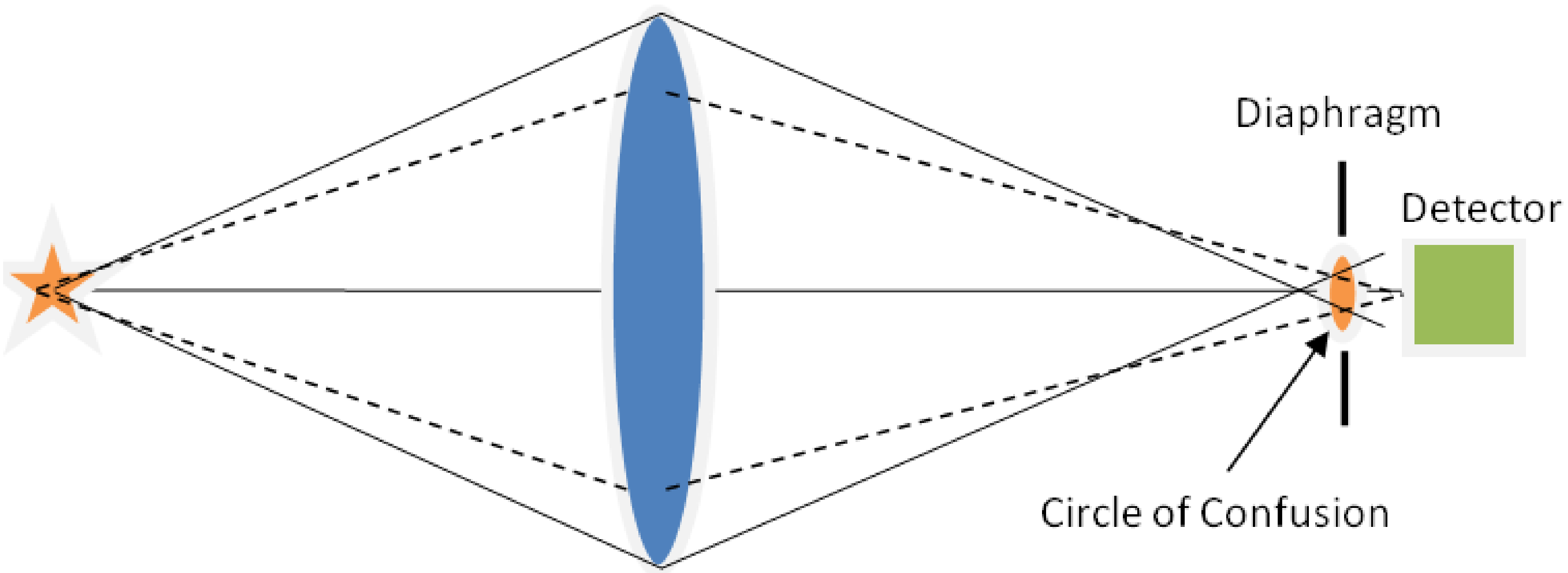
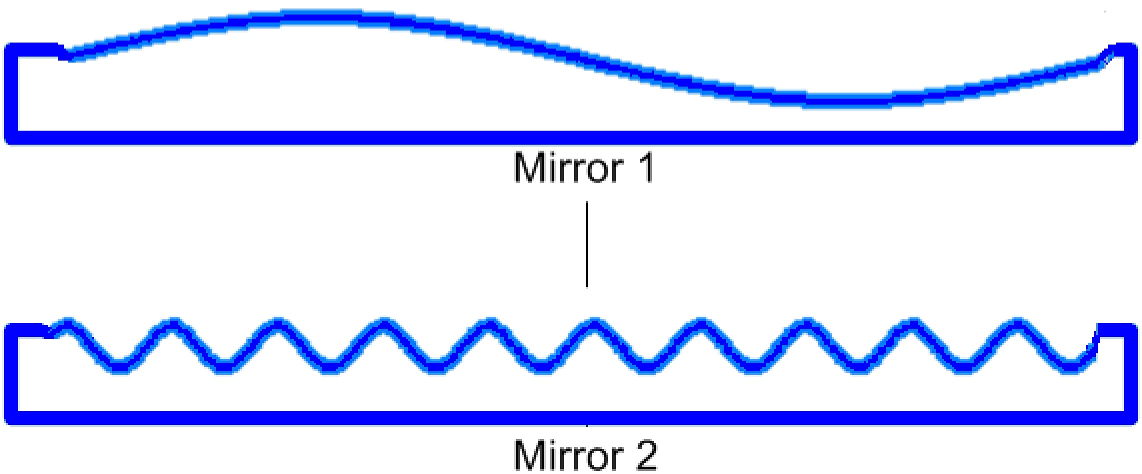
Circle of Confusion



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

Aberration Characterization I

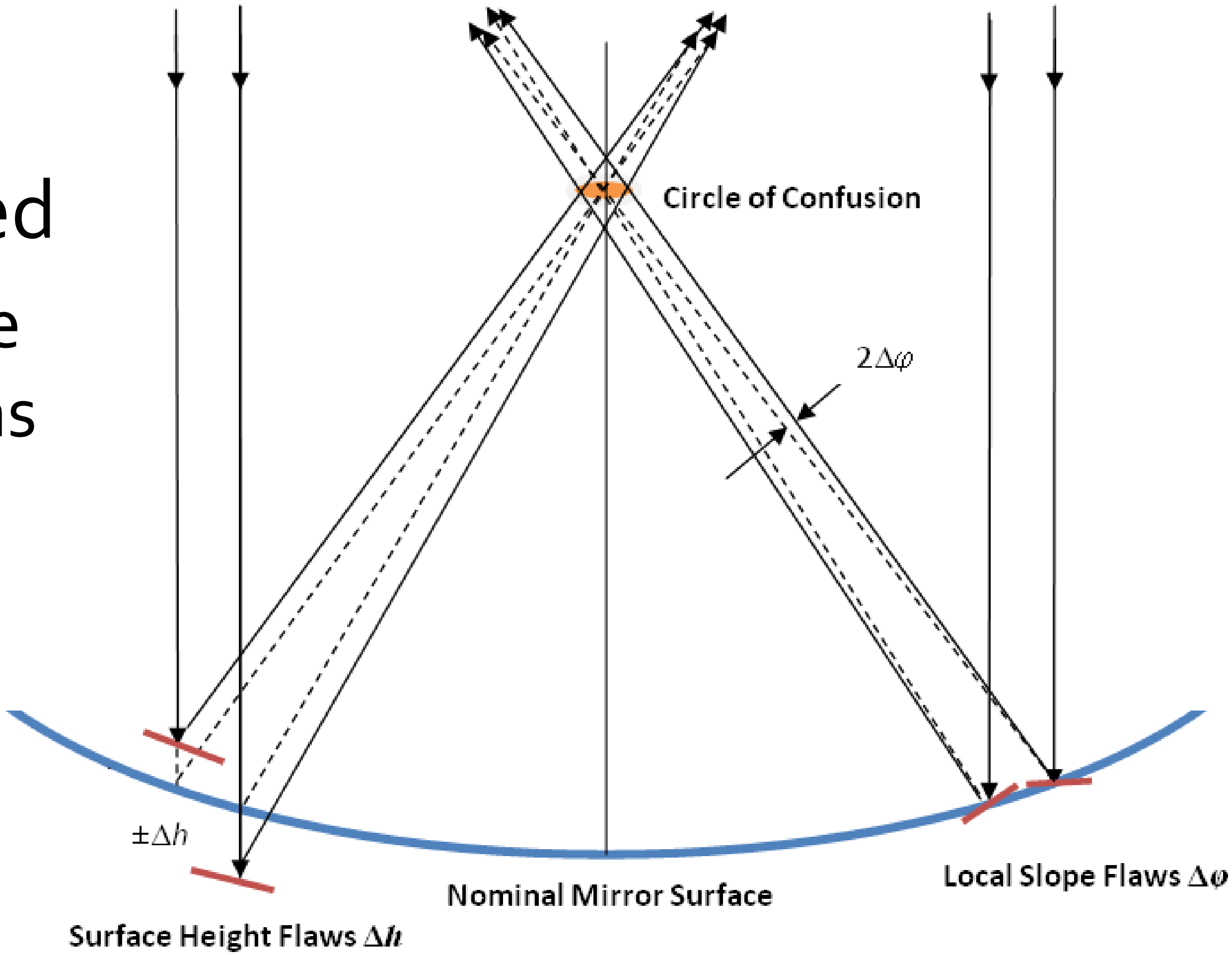
- Tools were needed to characterize progress and failure in our work
  - Traditional quantification such as P-V and Strehl Ratio were not helpful



P-V and RMS measures are the same for both mirrors!
But, not $|\Delta\varphi|_{rms}$ (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(ρ,θ)*, is used for the estimation of **σ** and $|\Delta\boldsymbol{\varphi}|_{\mathbf{rms}}$
- **1** $$W(\rho,\theta) = \sum_j a_j Z_j(\rho,\theta)$$
- **2** $$\sigma_W^2 = \langle W^2(\rho,\theta)\rangle - \langle W(\rho,\theta)\rangle^2 = \sum_{i=2} a_j^2$$
- **3** $$\nabla W(\rho,\theta) = \frac{\delta W}{\delta\rho}\,\boldsymbol{e_\rho} + \frac{1}{\rho}\frac{\delta W}{\delta\theta}\,\boldsymbol{e_\theta}$$
- **4** $$|\Delta\phi|_{rms} = \frac{\|\nabla W\|_{rms}}{D/2}$$

Aberration Characterization V

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

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

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

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 ~ 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					
			"E"	RMS Wavefront Gradient	Ratio
j	**Type**	**Polynomial**	**P-V**	$\lVert \nabla W_j \rVert_{rms}$	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	45º Astigmatism	$\sqrt{6}\rho^2\ sin2\theta$	$2\sqrt{6}\ a_5$	$2\sqrt{3}\ a_5$	0.7
6	0º Astigmatism	$\sqrt{6}\rho^2\ cos2\theta$	$2\sqrt{6}\ a_6$	$2\sqrt{3}\ a_6$	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	30º Trefoil	$2\sqrt{2}\rho^3\ sin3\theta$	$4\sqrt{2}\ a_9$	$4\sqrt{6}\ a_9$	1.7
10	0º Trefoil	$2\sqrt{2}\rho^3\ cos3\theta$	$4\sqrt{2}\ a_{10}$	$4\sqrt{6}\, a_{10}$	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)?

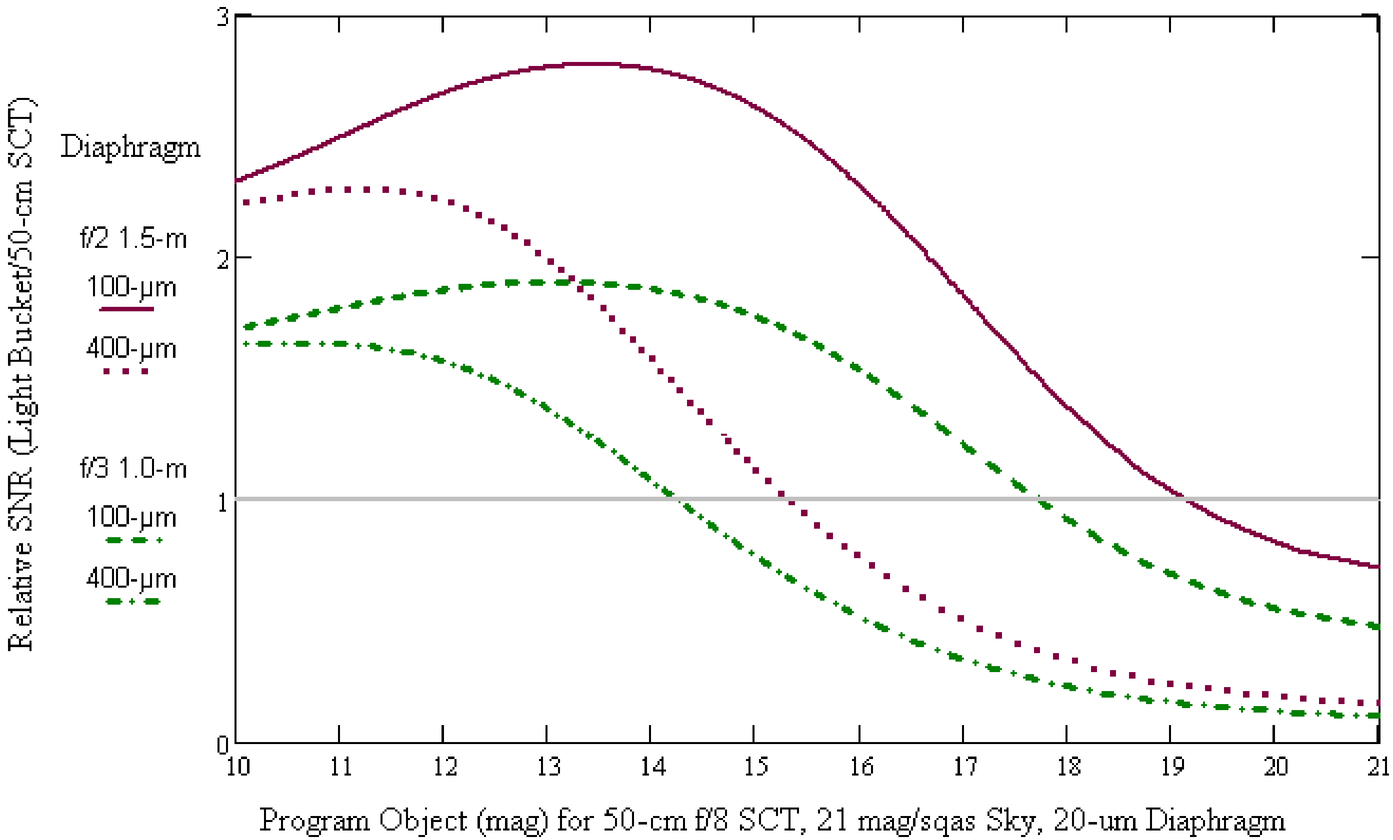
$$SNR = \frac{N_{Star+Sky} - N_{Sky}}{\sqrt{N_{Star+Sky} + N_{Sky} + N_{Detector} + S^2}},$$

where *Ns* are counts and *S* models atmospheric scintillation

- Focal plane diaphragm size

Light Bucket vs. SCT

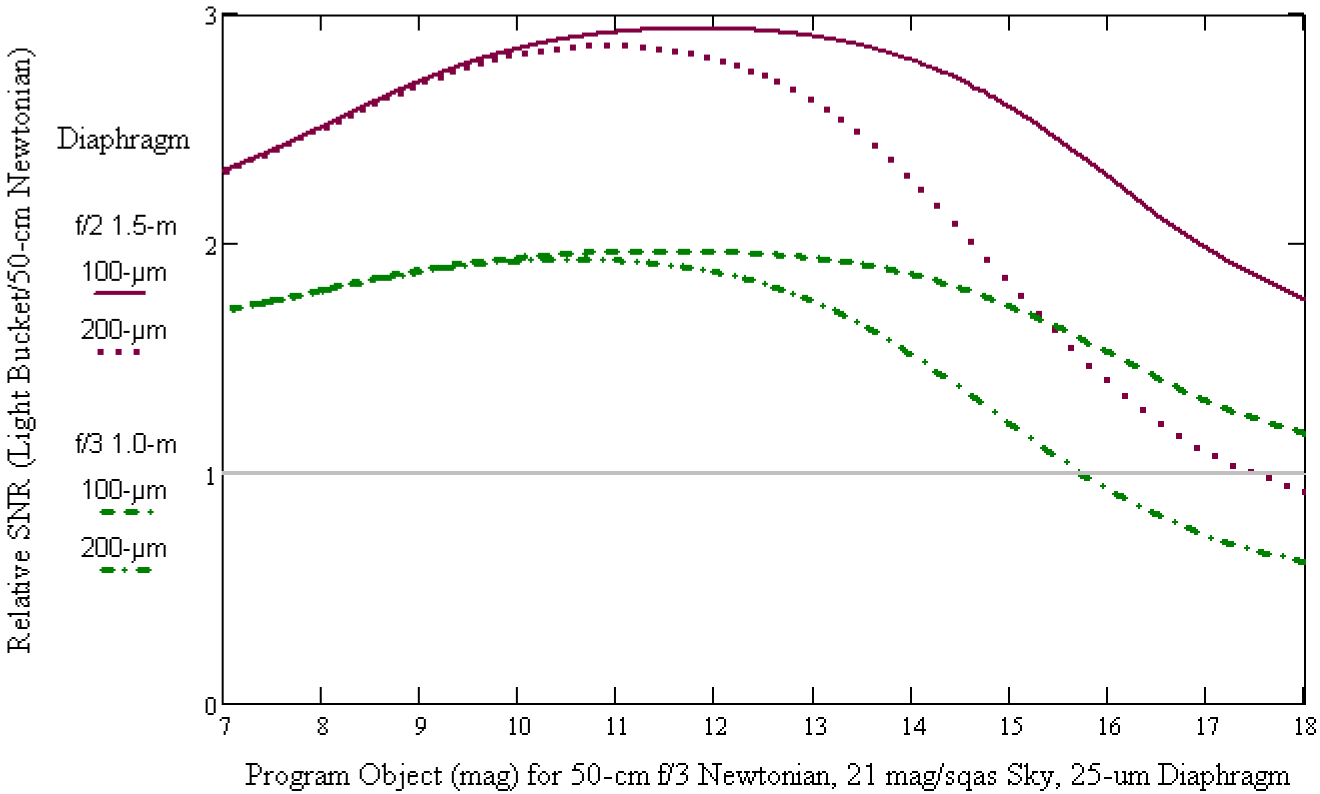
- Traditional f/8 SCT, 0.50-m mirror
- Light bucket f/2, 1.5-m & f/3 , 1.0-m
- Diaphragms - 28″&7″ vs. 1″ on SCT
- Scintillation at 1000-m, air-mass 1.5



SAS 2010 LBA paper

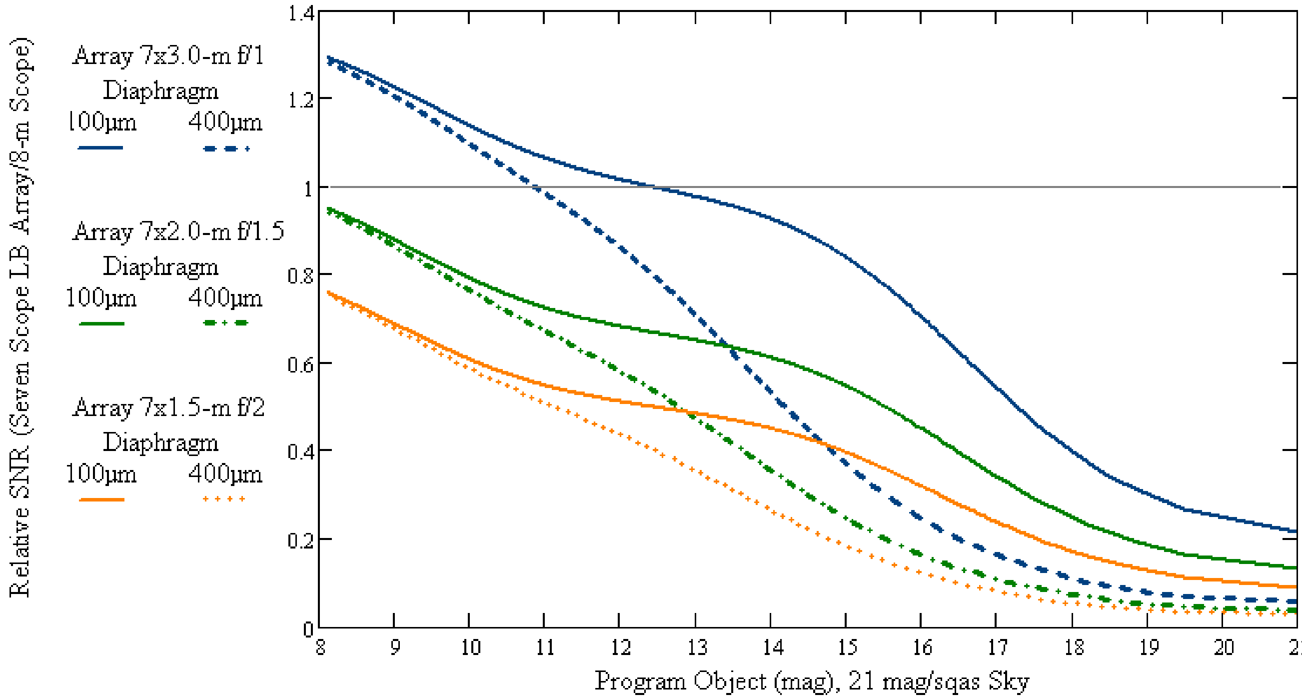
Light Bucket vs. Newtonian

- 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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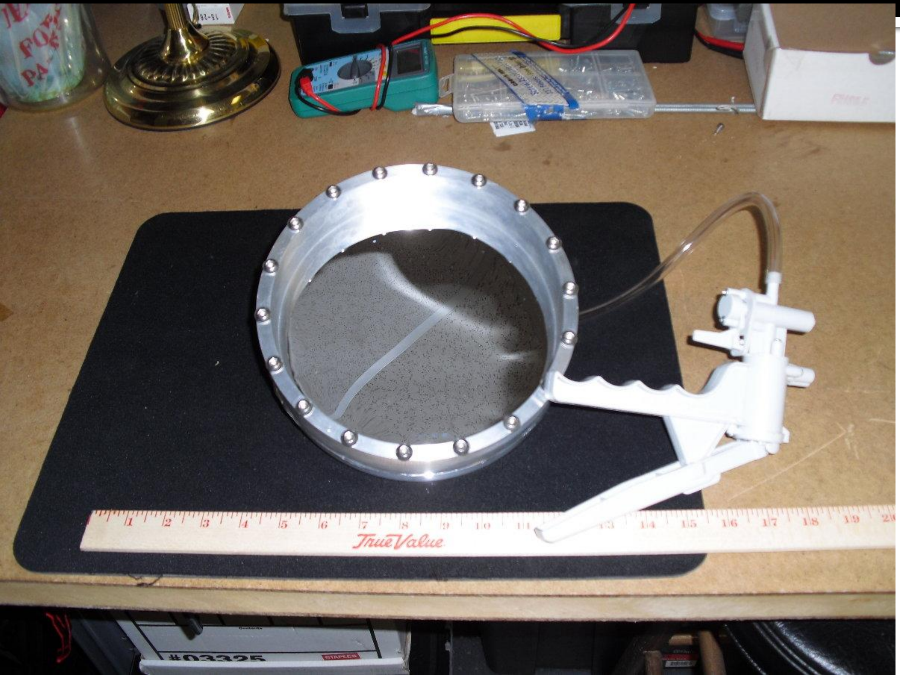
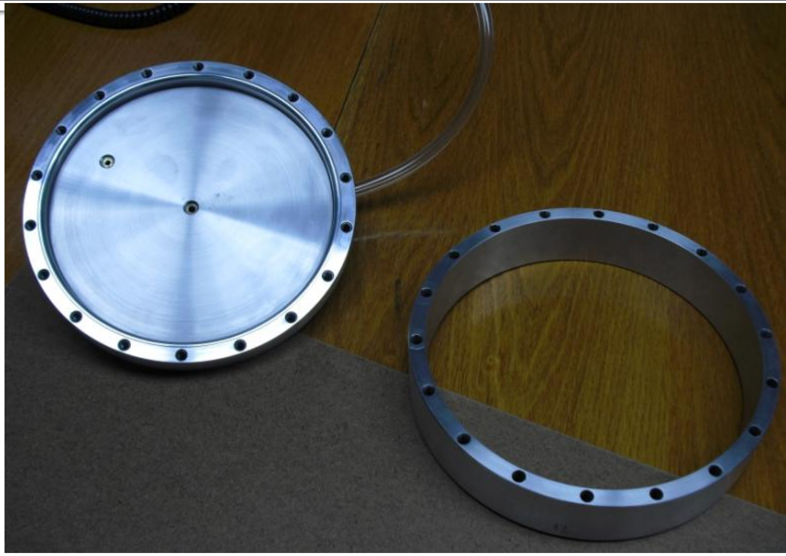
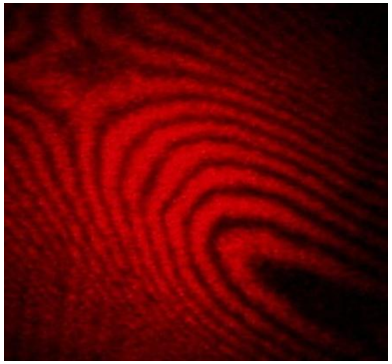
Might be interesting to have an intern see how many of these companie still use NonStop

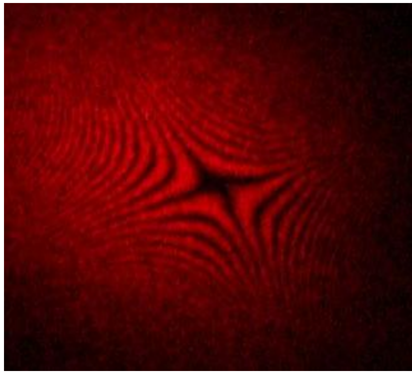
Light Bucket Mirrors I





- 7" pneumatic mirror
- Complex interferograms





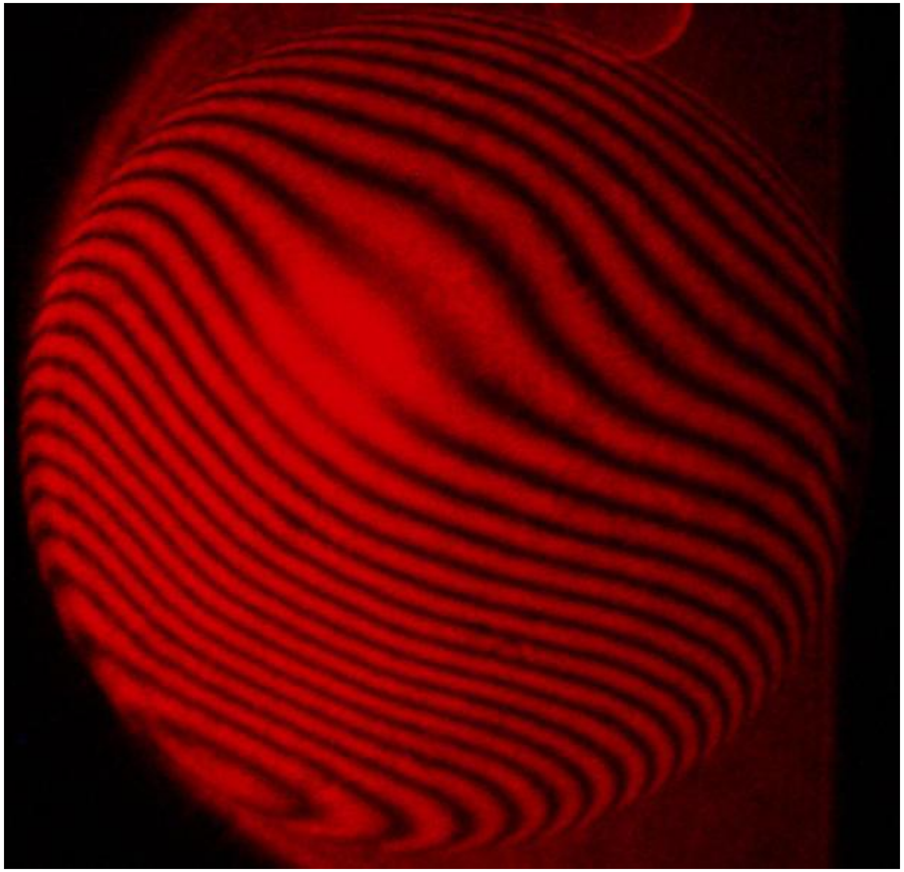
Light Bucket Mirrors II

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

Light Bucket Mirrors III

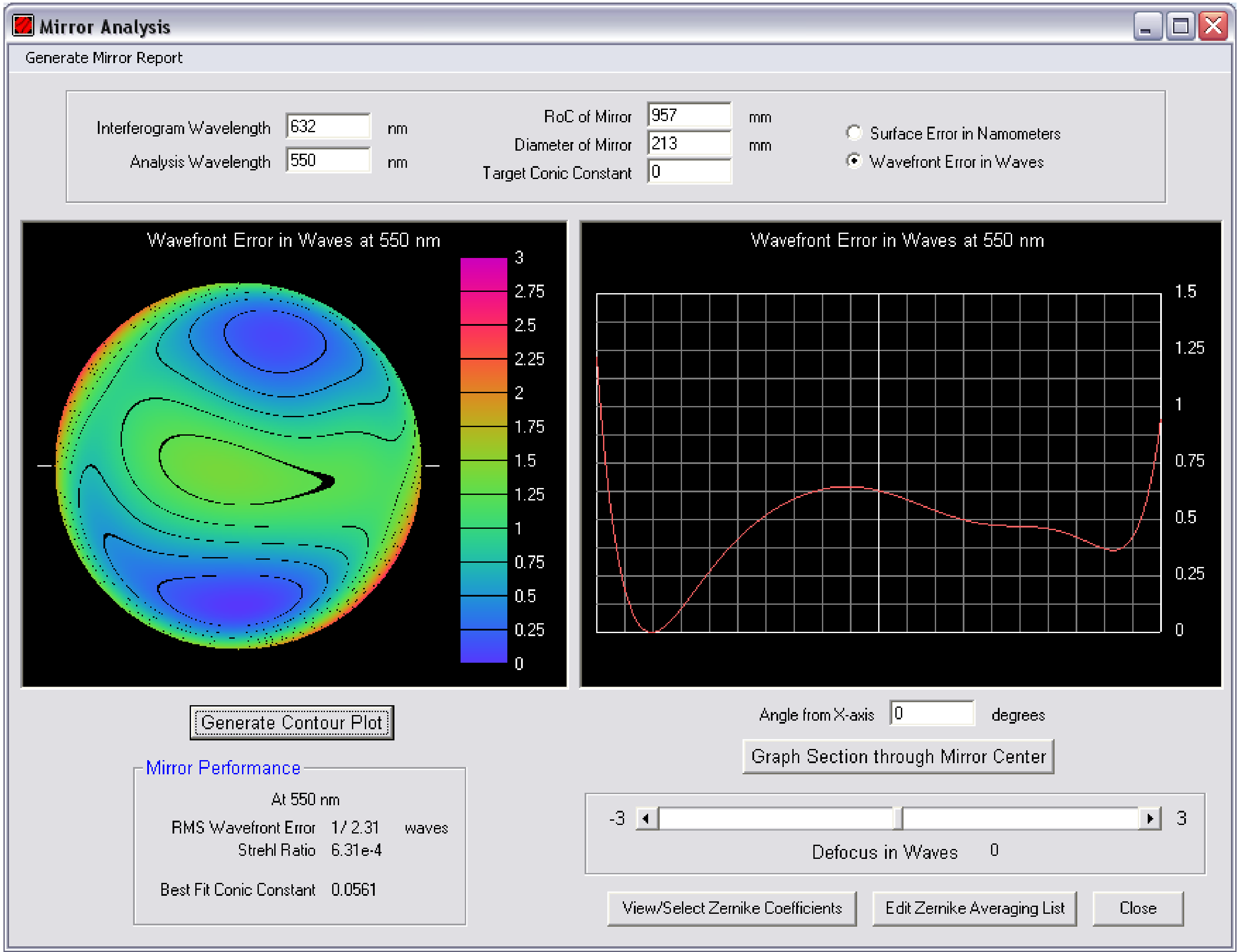
- Our first 1-meter light bucket…

Starstone evaluation I



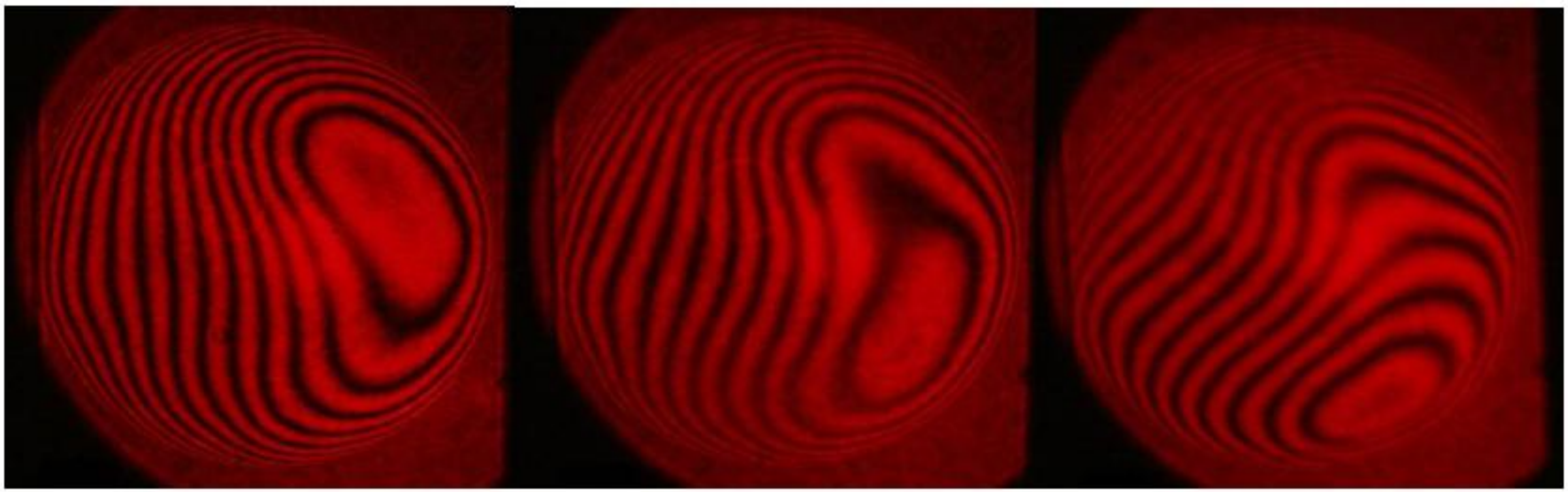
- Mirror 0001A 8″ f/2.25

Starstone evaluation II



Starstone evaluation III

- Cooling after 30 sec. warming with heat gun

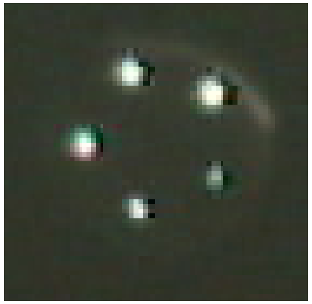


7:32:26pm 7:32:54pm 7:33:52pm

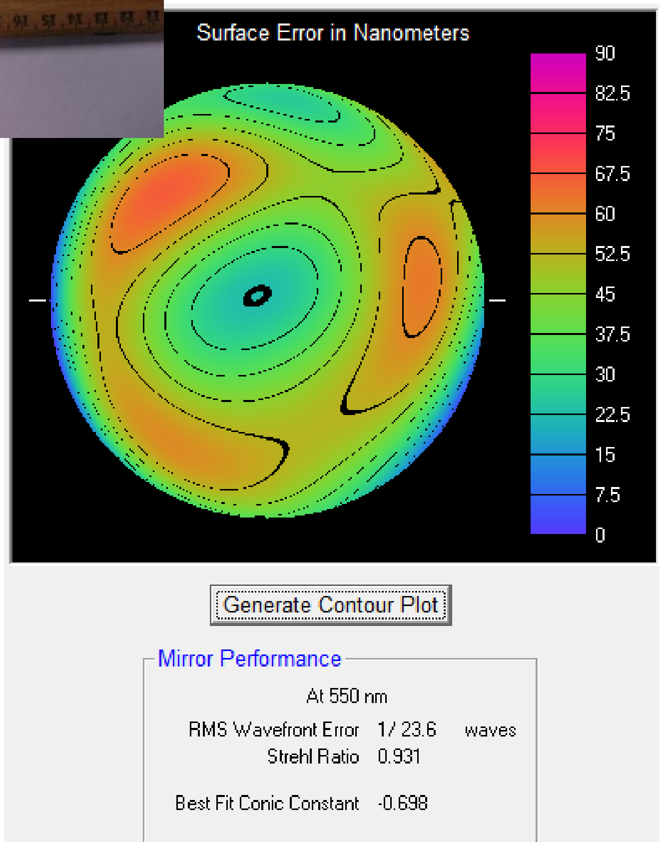
Starstone evaluation IV

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

- 25" – with correction



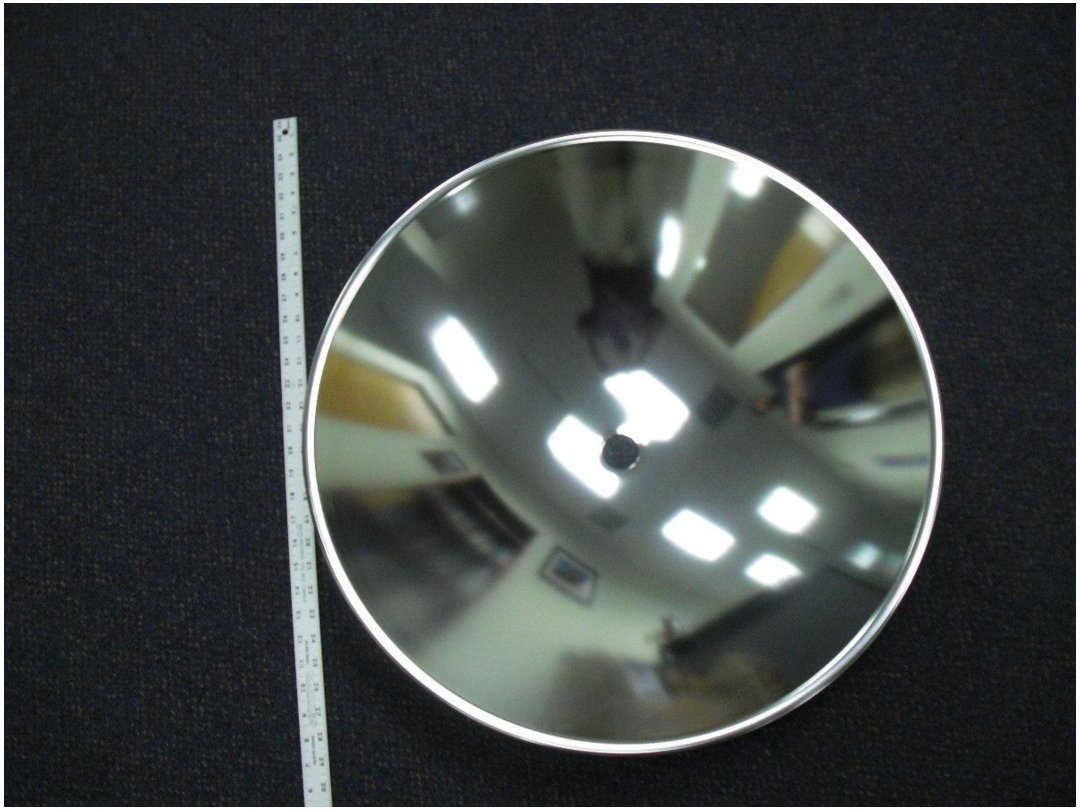
Peacock Labs I



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

Other Potential LBT Mirrors

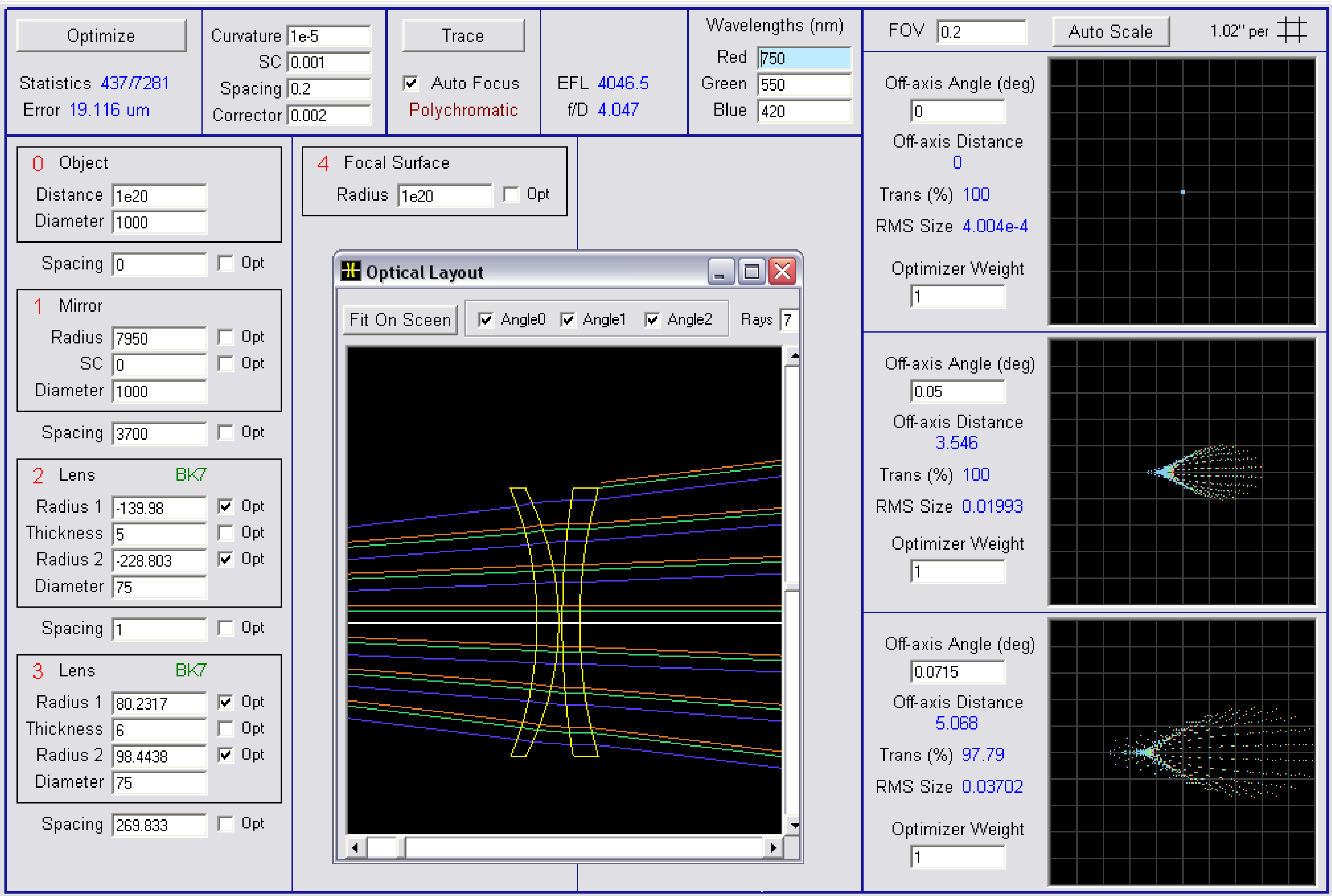
- Edmund 24″ parabolic
- Aluminum 0.04″
- f/0.25
- 1.5″ central hole
- Low reflectivity (not "precision polished")



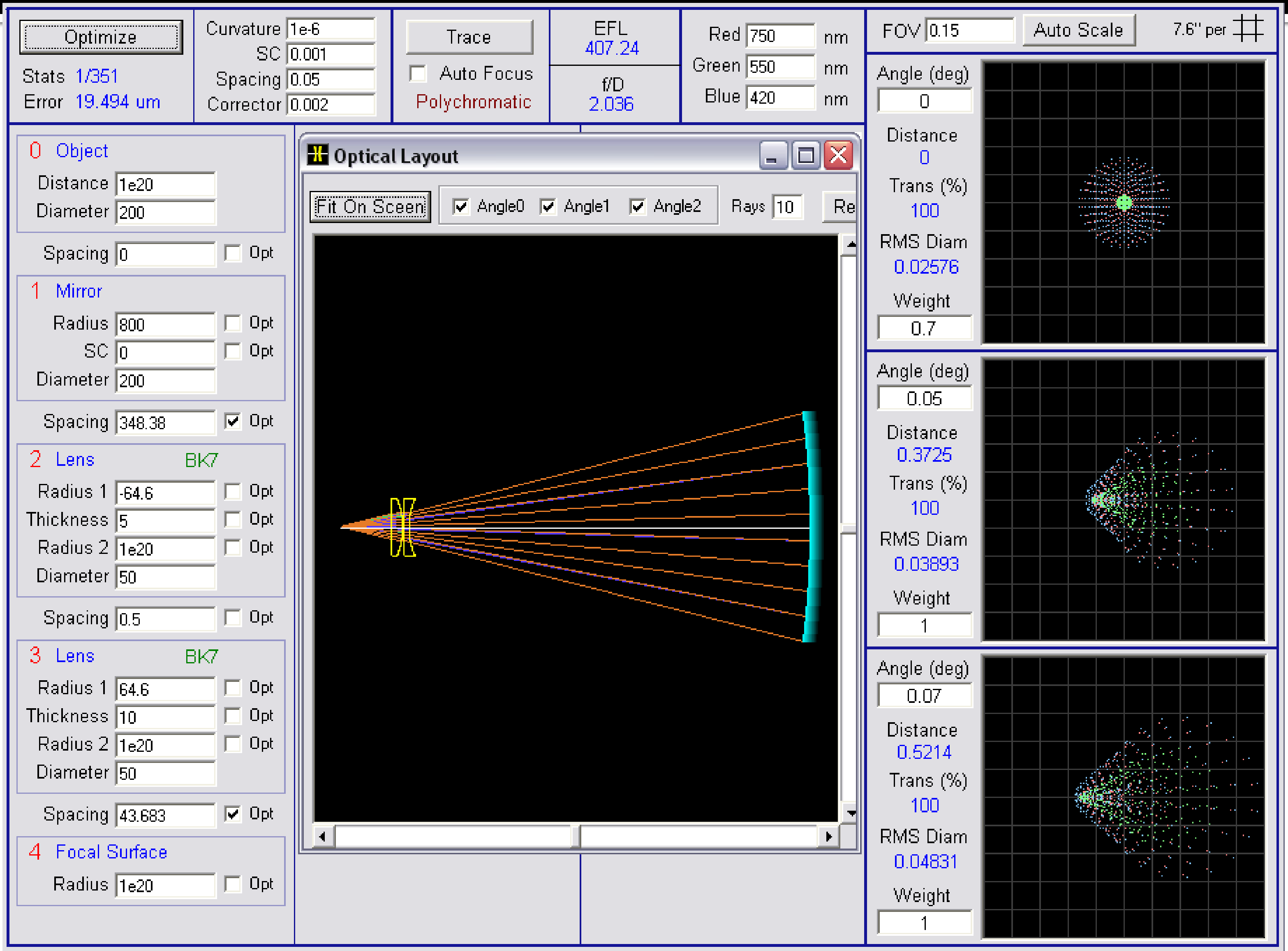
Correctors

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

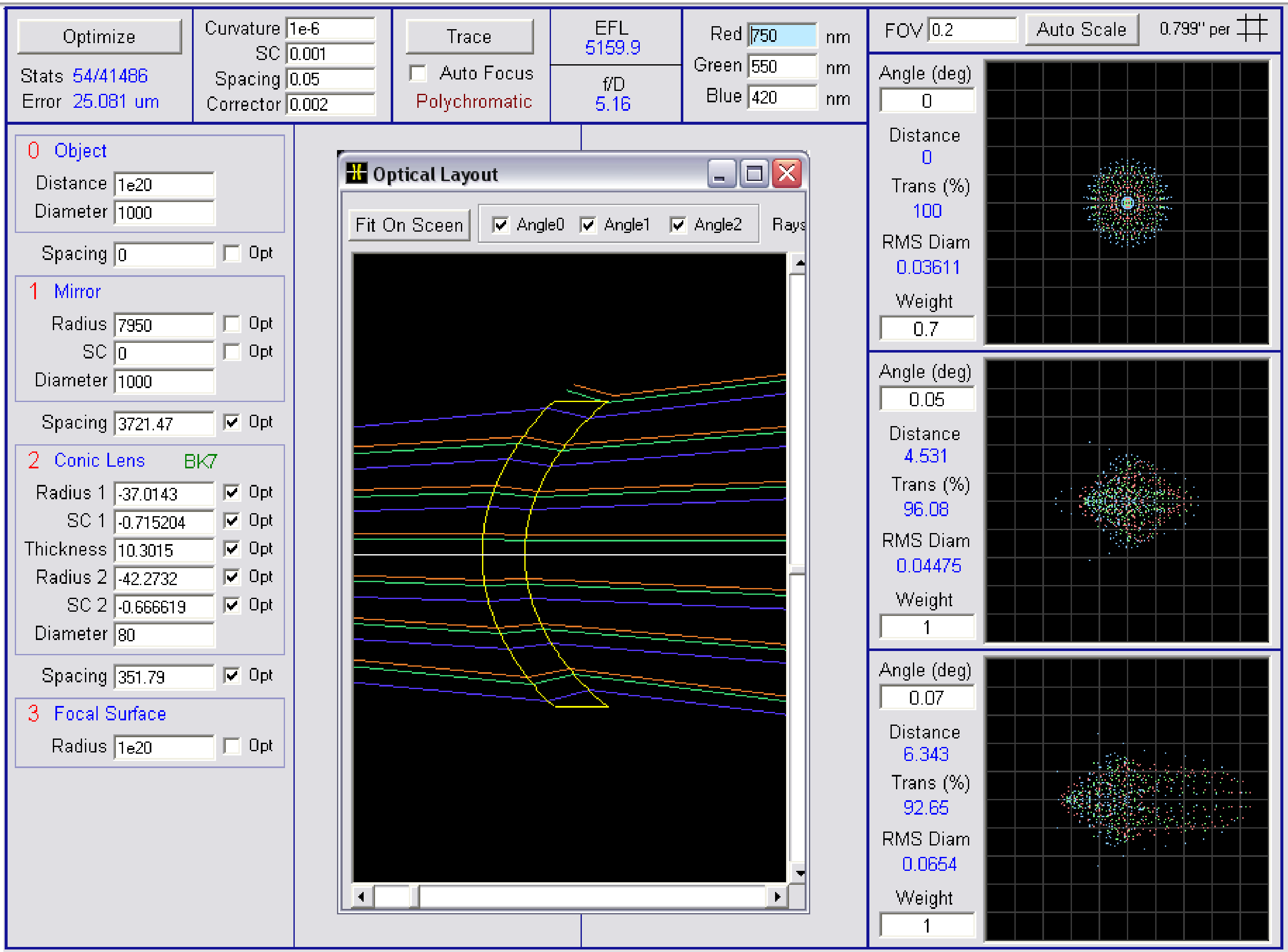
Dave Rowe's 1-m, f/4 Corrector



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

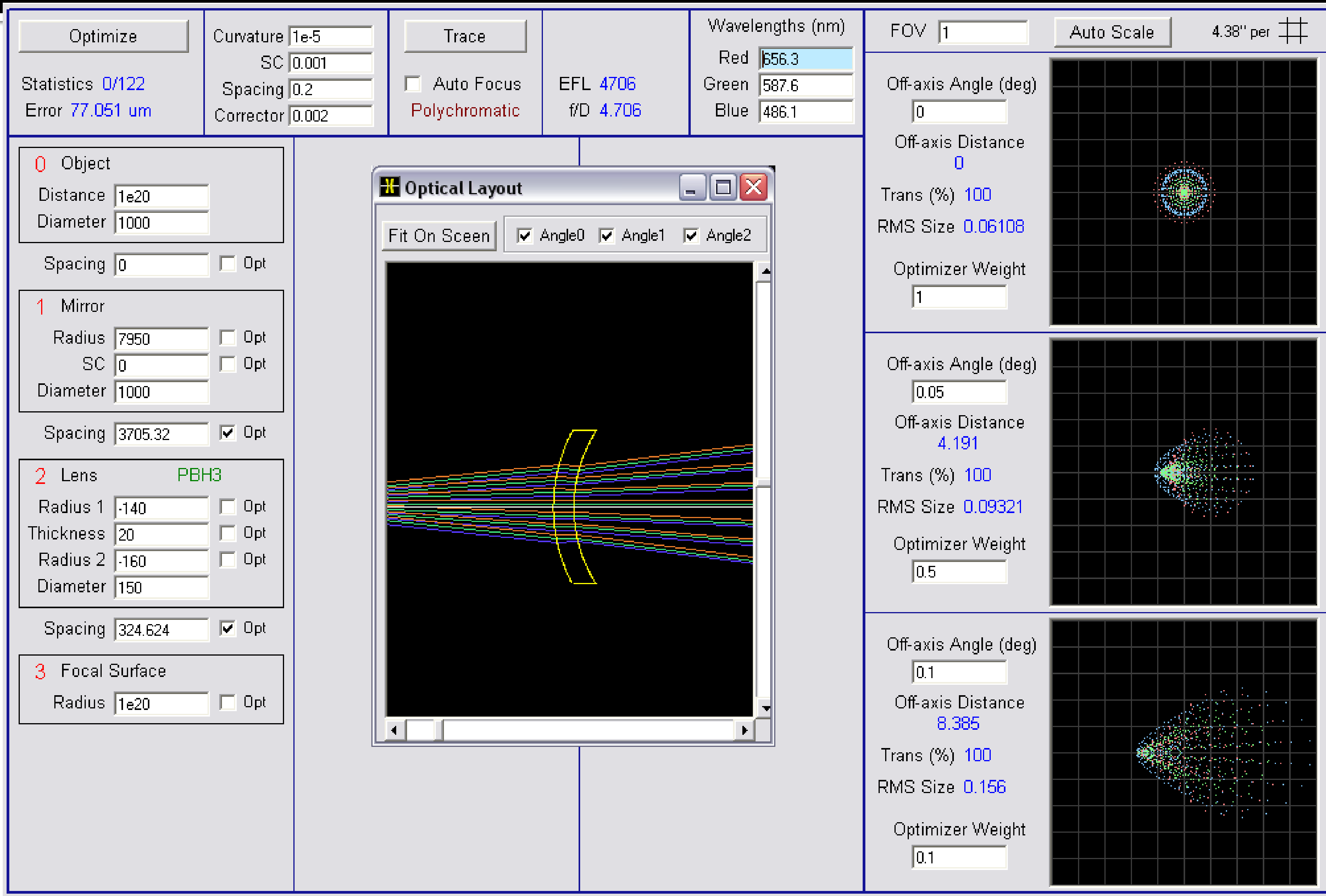


1-m f/4 BK4

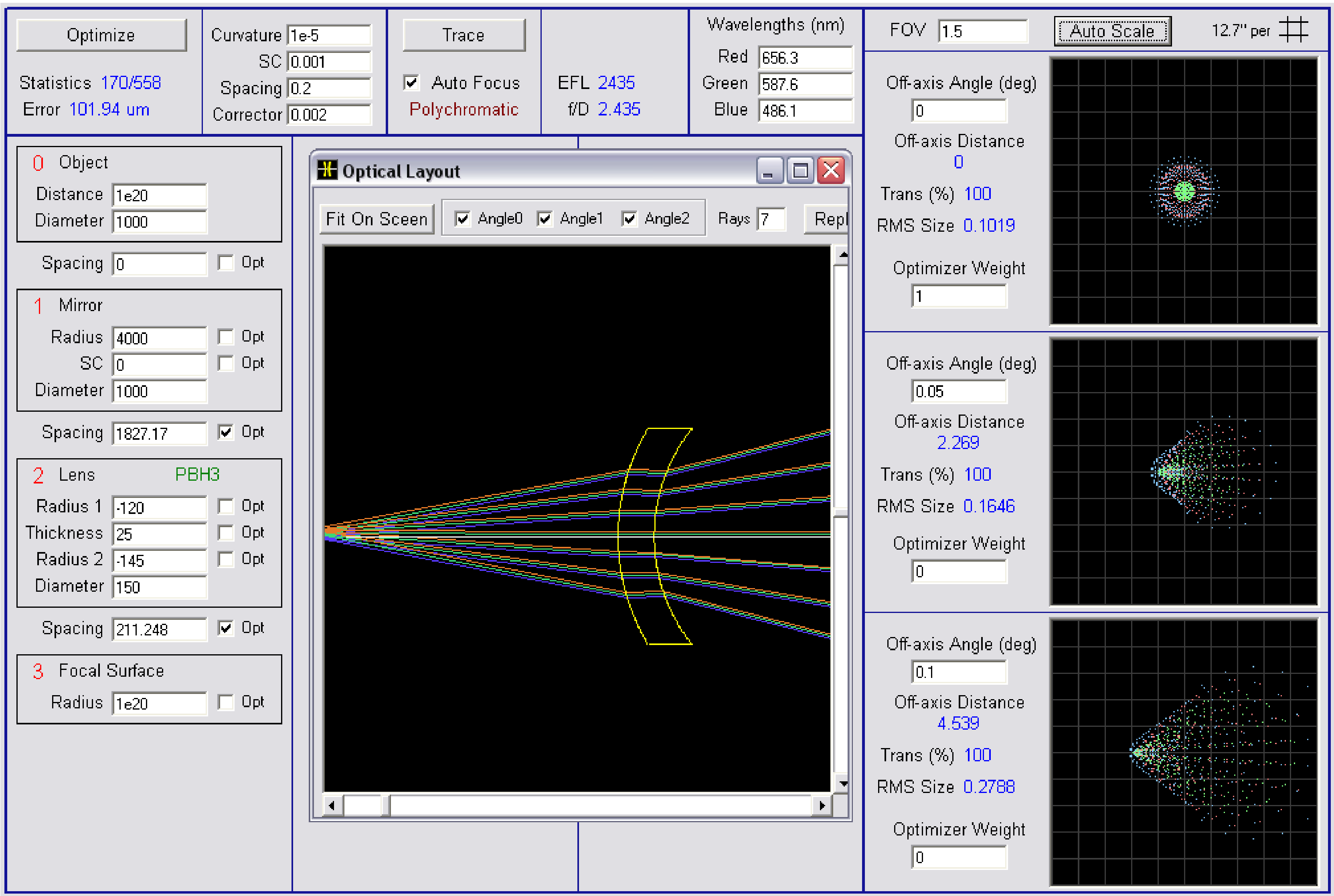


Optimize
Stats 54/41486
Error 25.081 um
Curvature 1e-6
SC 0.001
Spacing 0.05
Corrector 0.002
Trace
Auto Focus
Polychromatic
EFL 5159.9
f/D 5.16
Red 750 nm
Green 550 nm
Blue 420 nm
FOV 0.2
Auto Scale
0.799" per
0 Object
Distance 1e20
Diameter 1000
Spacing 0 Opt
1 Mirror
Radius 7950 Opt
SC 0 Opt
Diameter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

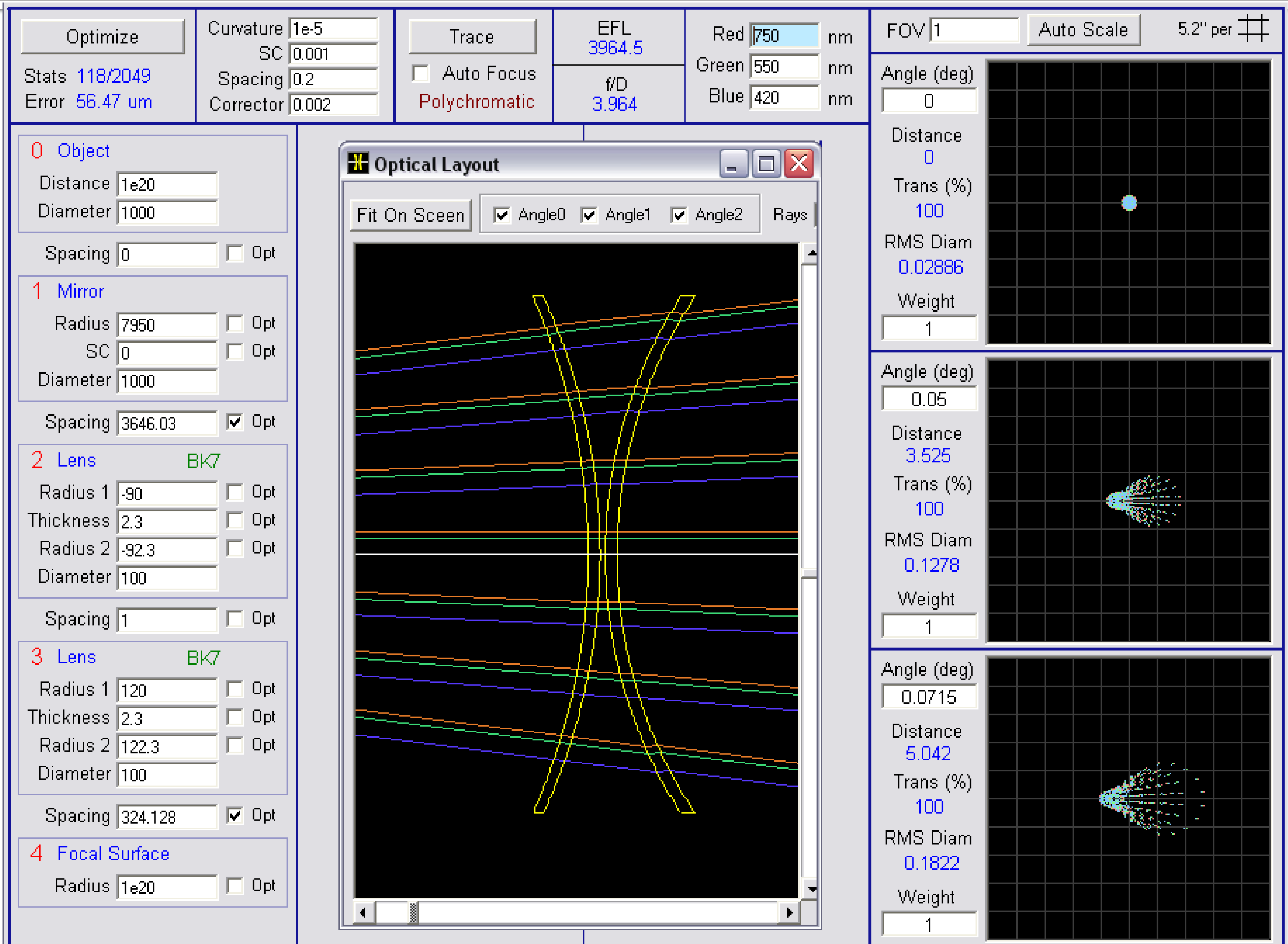
1-m f/4 Plastic



1-m f/2 Plastic

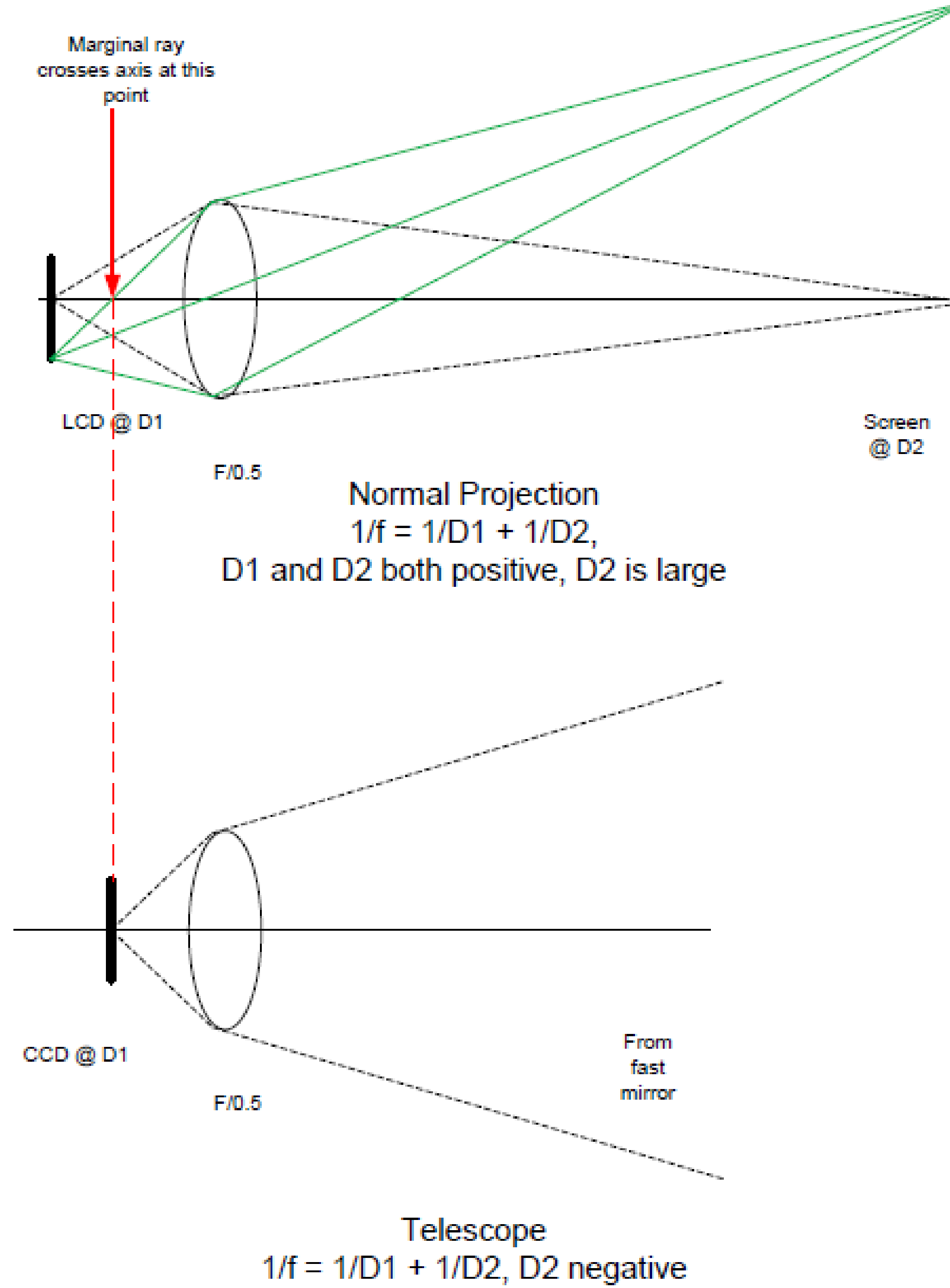


1-m f/4 Meniscus



Aspherics

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

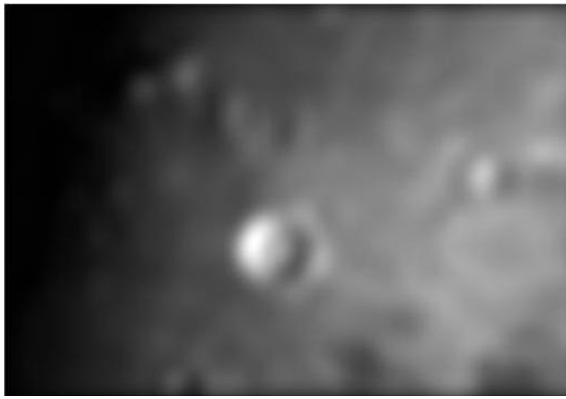


Gaussian Kernel I

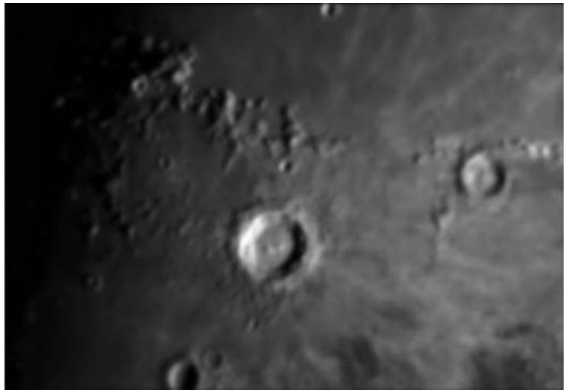
Above : Russ's 1-m f/4 w/no correction

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

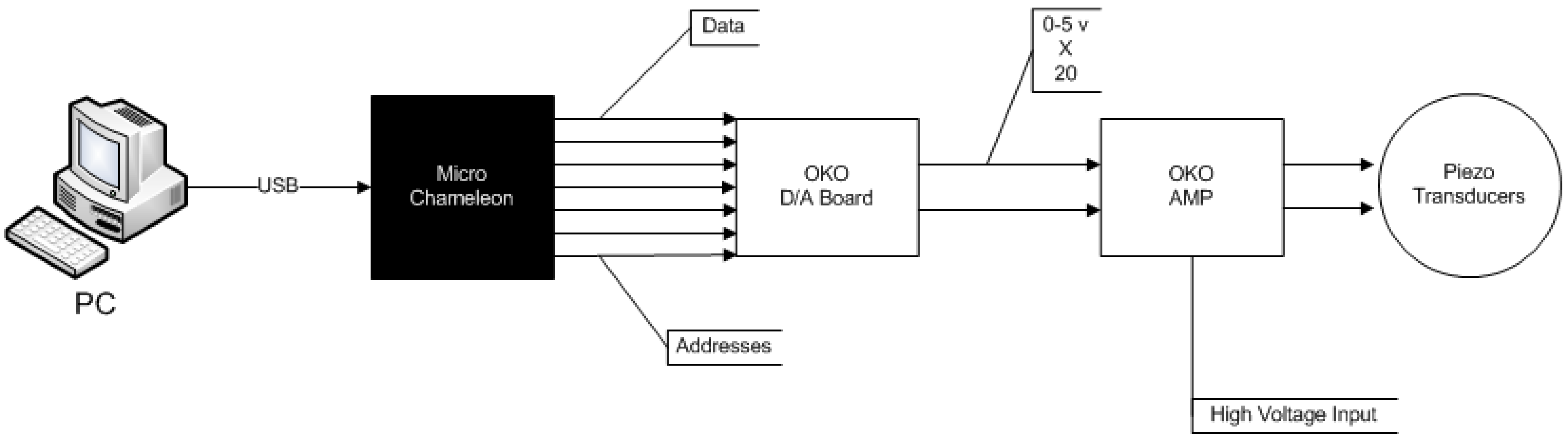
- Albirio pair – 35″ apart
- Middle and right images correspond to the lunar ones on the previous slide.

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°
  - 40 actuators

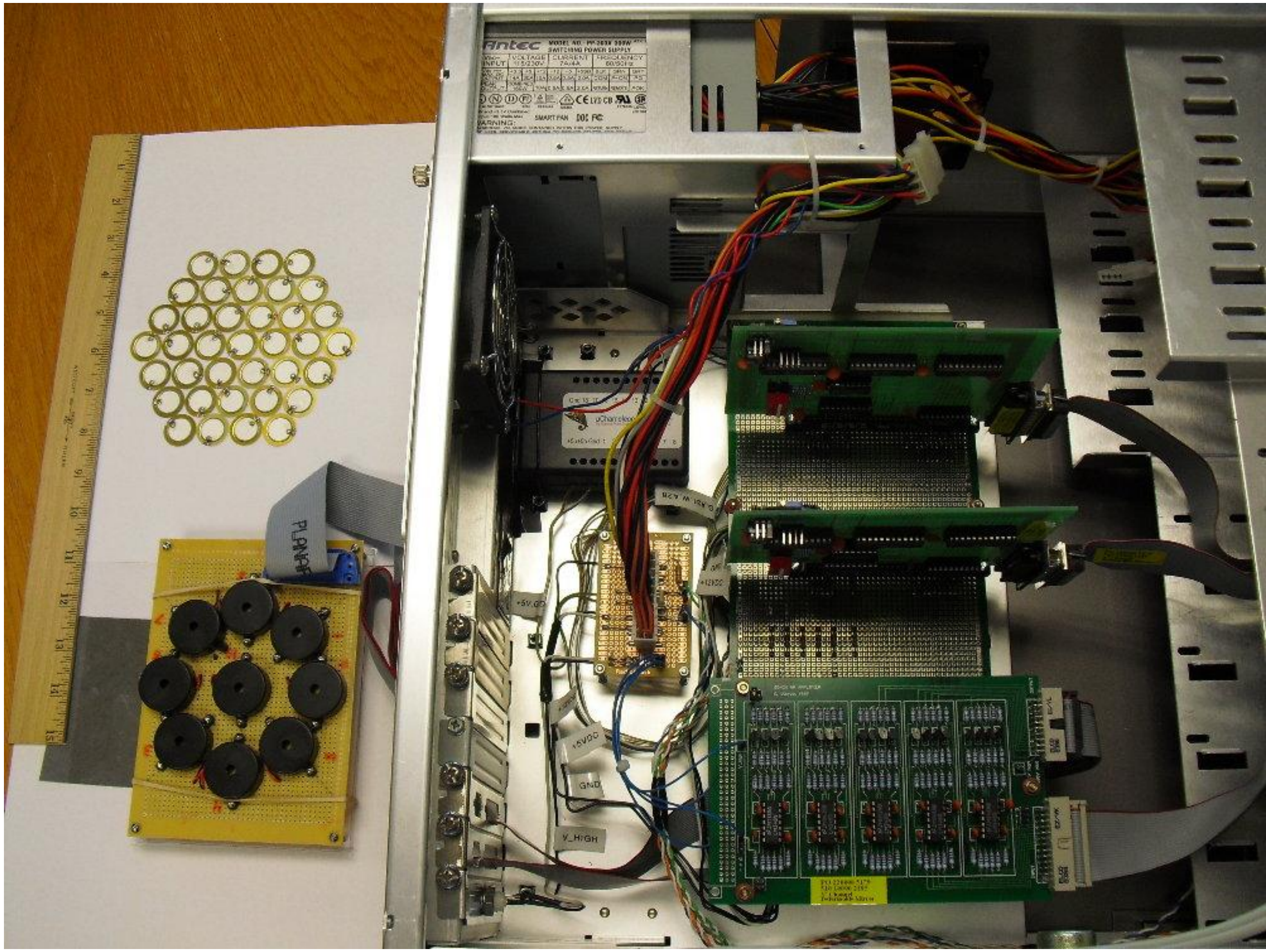
Deformable Mirrors II

- Controller



Deformable Mirrors III

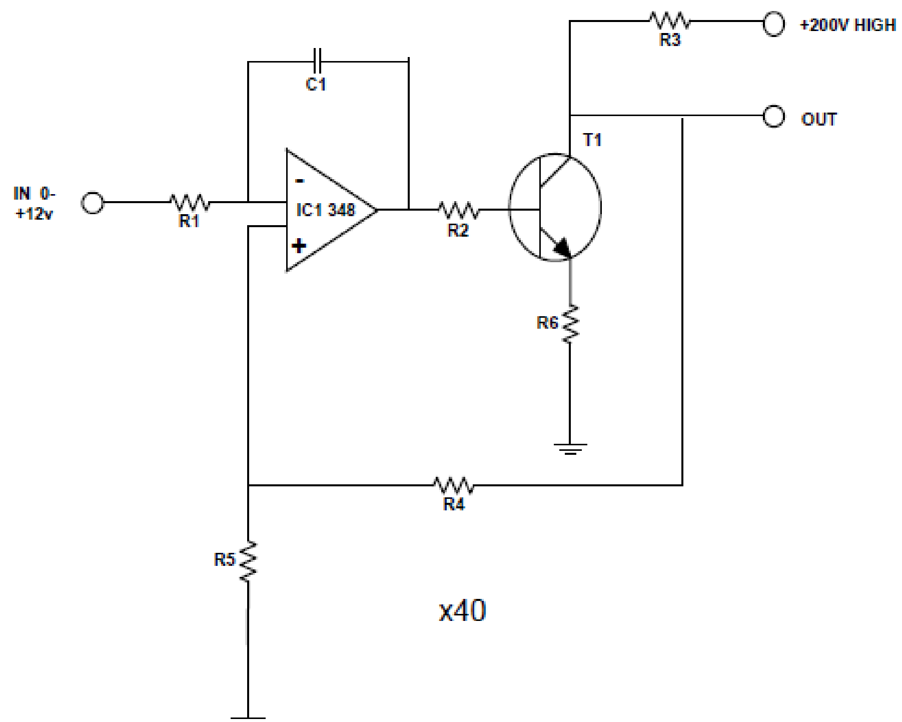
- Re-used old ISA OKO boards
- USB µChameleon
- 500Hz update rate
- 40-channel
- 0-200v Out



Deformable Mirrors IV

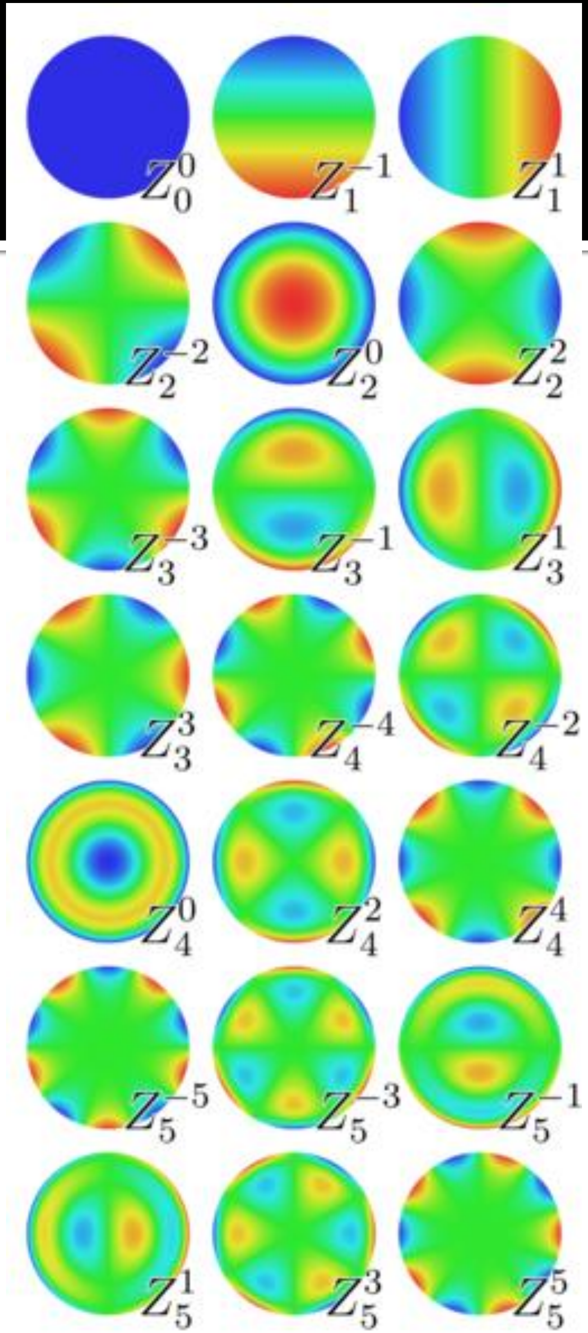
- HV amp: 0-3v in, 0-200v out
- 500Hz update rate
- MPSA42 @ $0.05ea. Qty. 2k

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



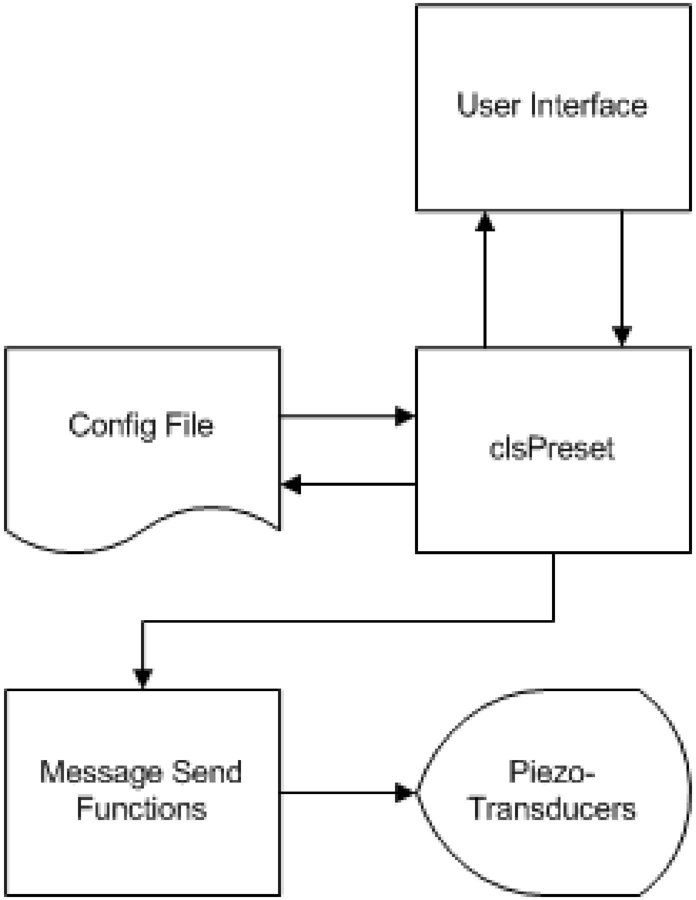
Deformable Mirrors V

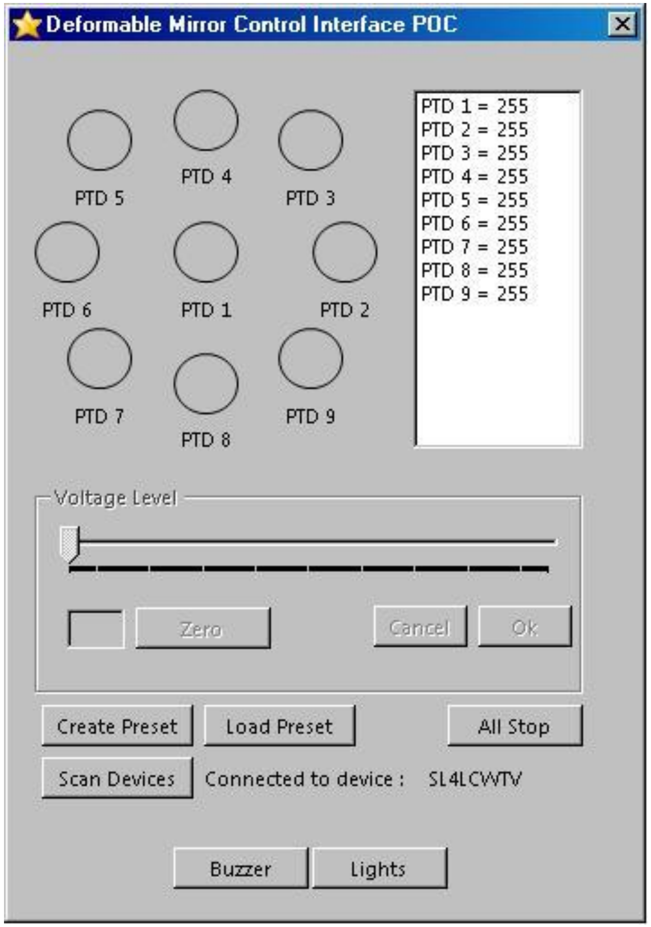
- Zernike orthonormal functions
- Closed loop
  - Wavefront sampling
  - Active correction
- Open loop
  - Minimize PSF (simulated annealing)
  - Lookup table



Deformable Mirrors VI

- Control Software





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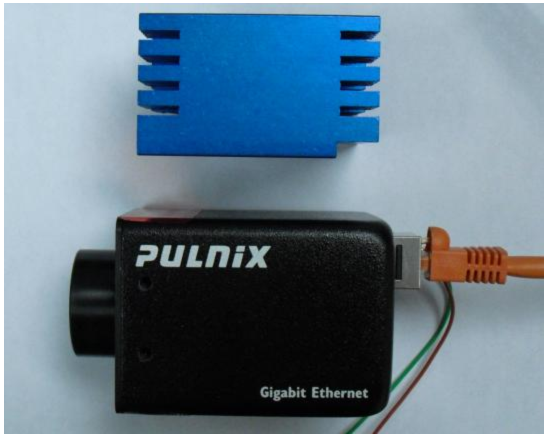
Fast Detectors

- 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)

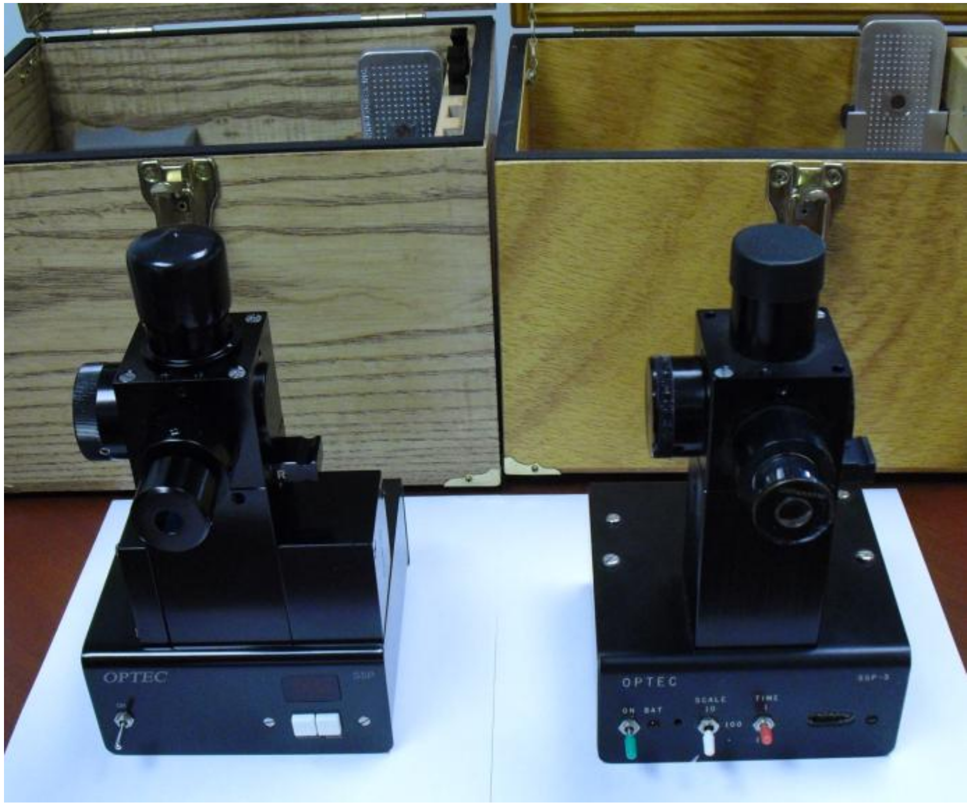
Detectors – Fast Area

- 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)

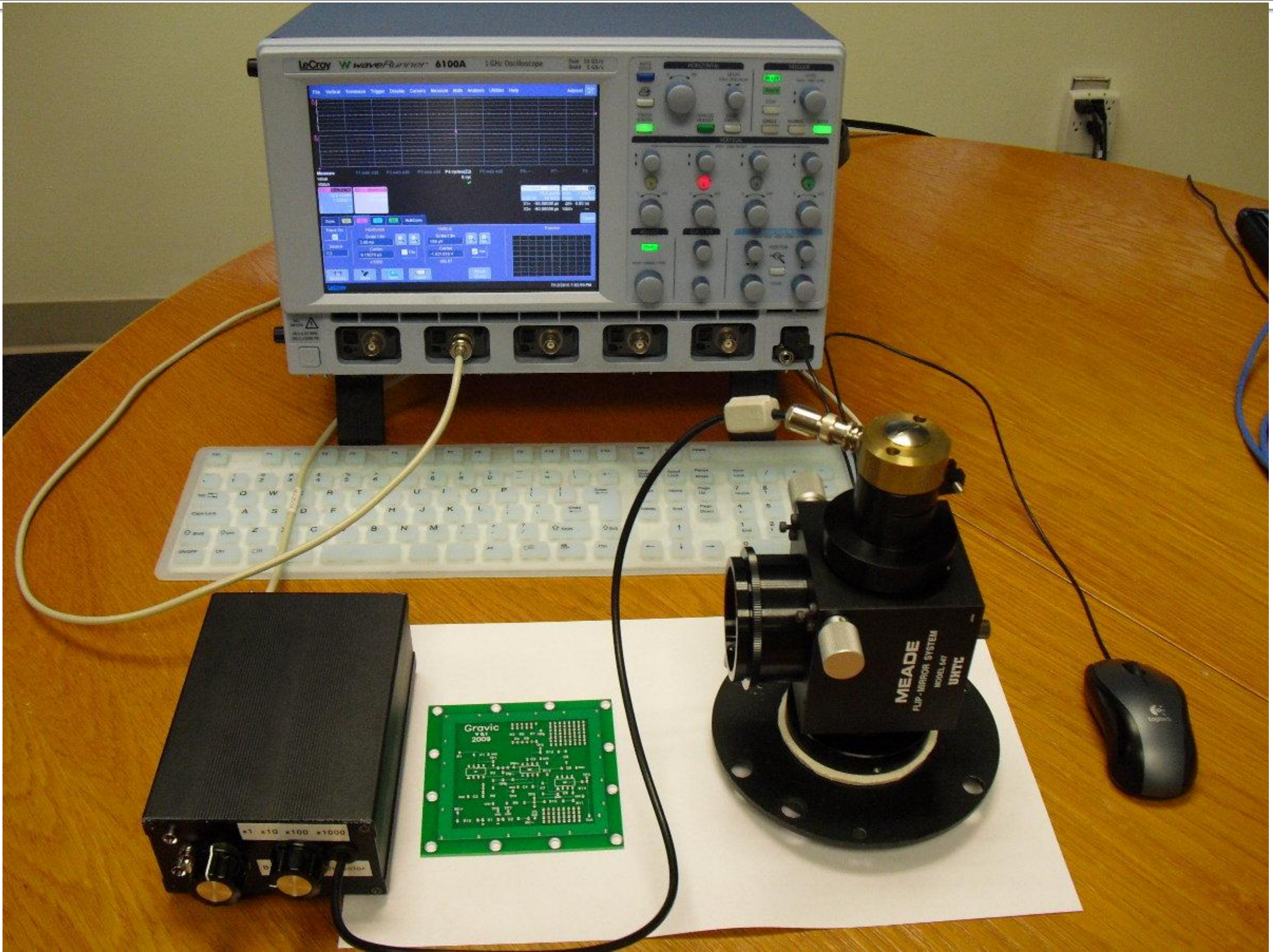


Diaphragm-limiting

- 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

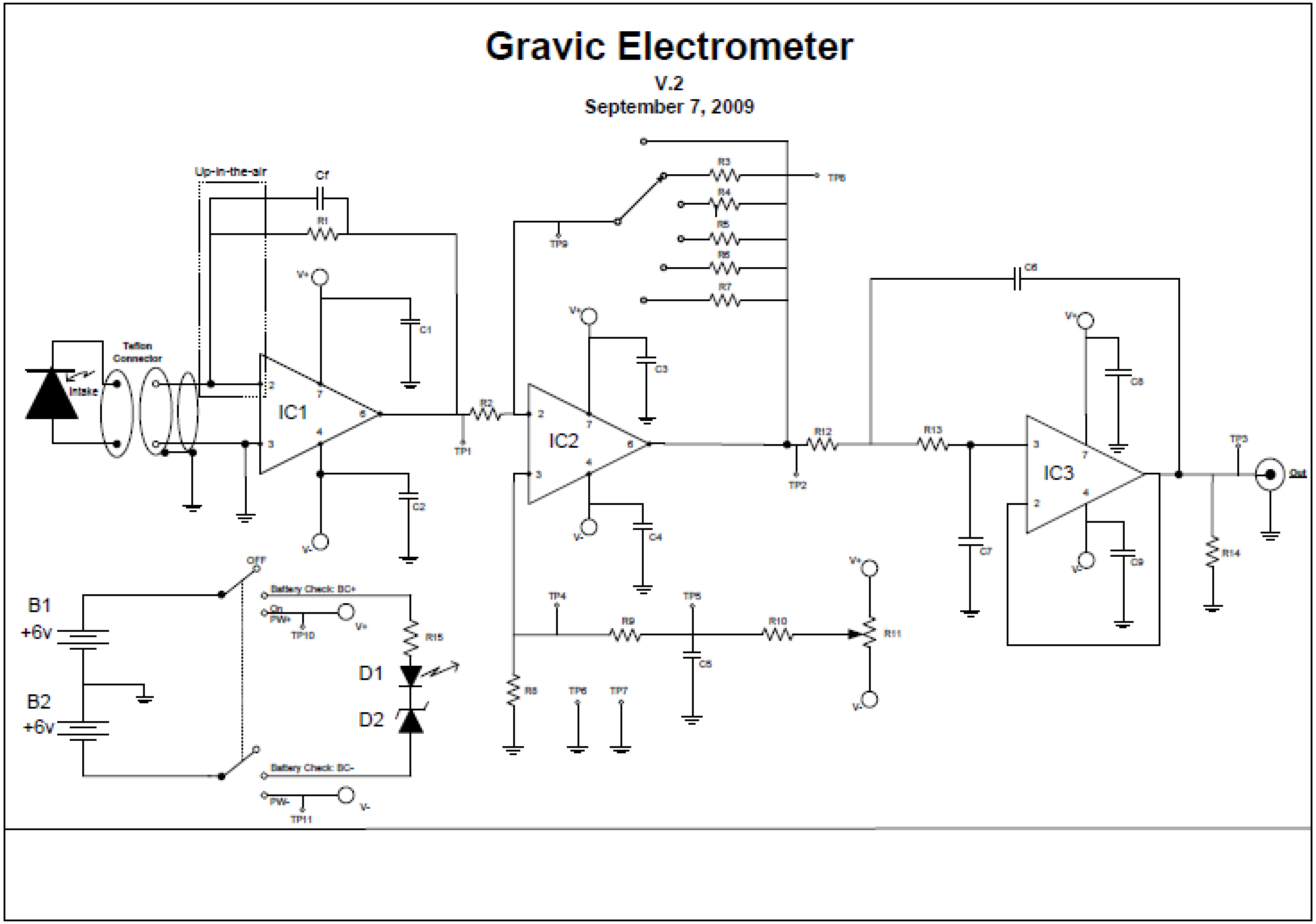


High Speed Electrometer I



High-Speed Electrometer II

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



Electrometer parts

- R1 – has to be modest to maintain BW

PARTS LIST

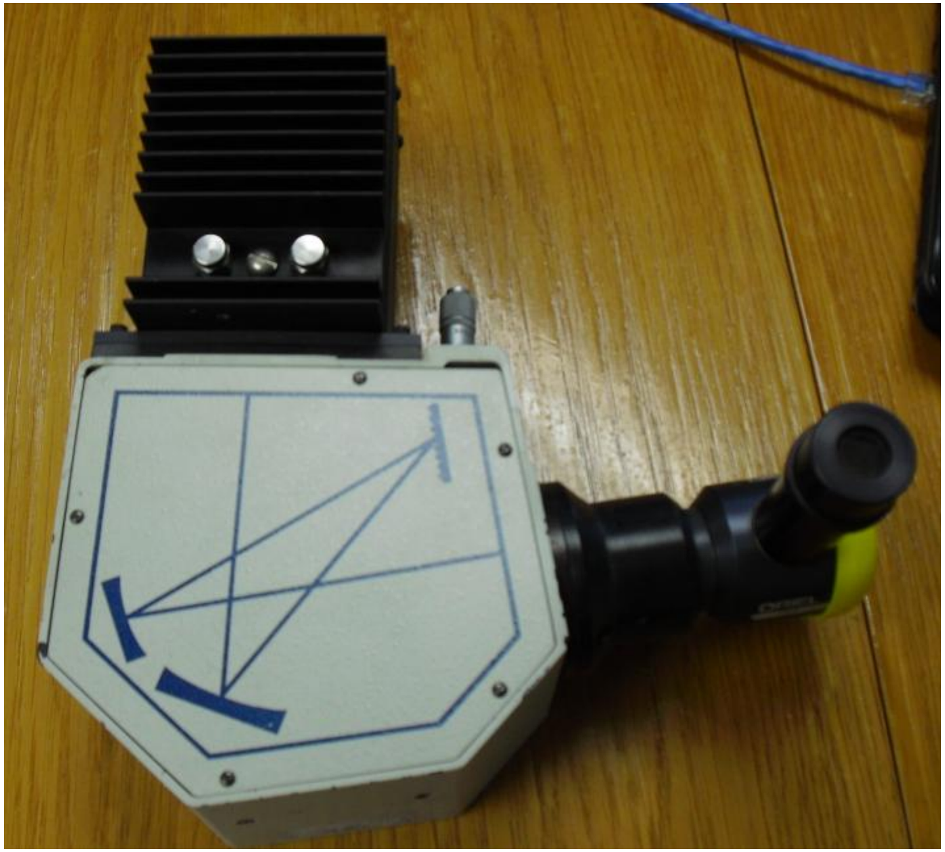
Resistor	Value (ohms)	Capacitor	Value (Farads)	Op Amp	Value	Battery	Value (volts)	Diode	Value
R1	5G, 1%	C1	.1u	IC1	LMC6081	B1	6	D1	LED - 10mA
R2	5k, 1%	C2	.1u	IC2	OPA621	B2	6	D2	ZENER - 9v
R3	5k, 1%	C3	.1u	IC3	OPA621				
R4	50k, 1%	C4	.1u						
R5	500k, 1%	C5	.1u						
R6	5M, 1%	C6	3u						
R7	50M, 1%	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
- NVIDEA CUDA GPU for photon correlation

Future experiments

- Oriel M125 Spectrograph (1/8 m)



Contact & More Information

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More details see:

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

2011 (scheduled) *Light Bucket Astronomy*