Optics

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- Performance
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  - Aberration
  - Ghost
  - Thermal
- Tolerance
- CCD

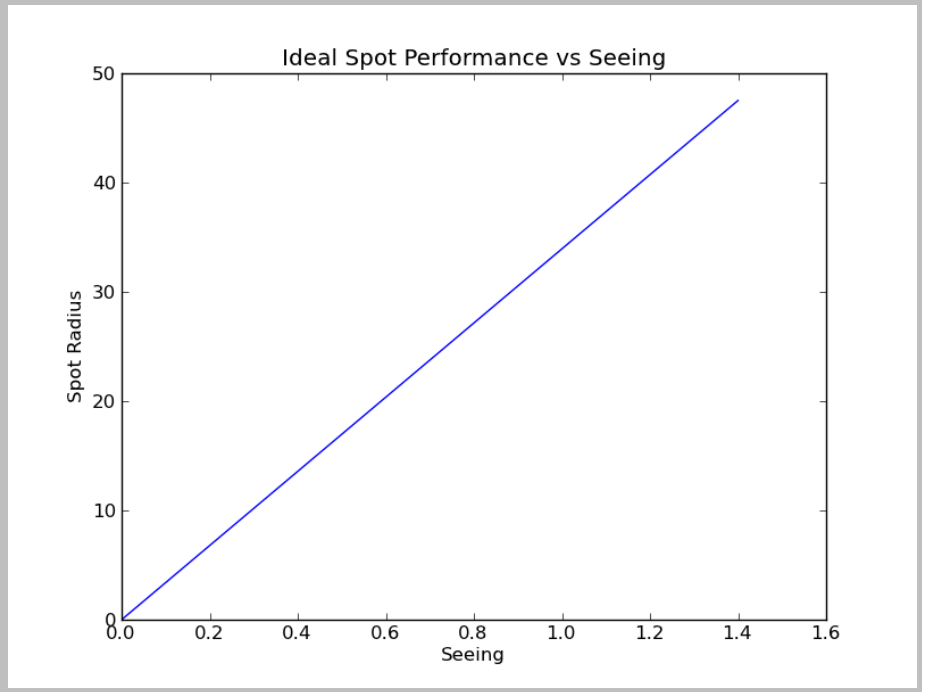
Introduction

- Focal reduction from telescope f/10.3 to f/8.0
- Spot size and ideal pixel size dictated by focal ratio
  - With a set pixel size we need to know the maximum spot size
  - Want to be Nyquist sampled, $f_s \geq 2 f_c$, at best seeing, chosen to be 0.6”
  - Maximum spot radius should be 20.3µm

$$spot\_radius = \frac{1000 * f/ * aperture * f_s}{206265} \frac{\mu m}{pixel}$$

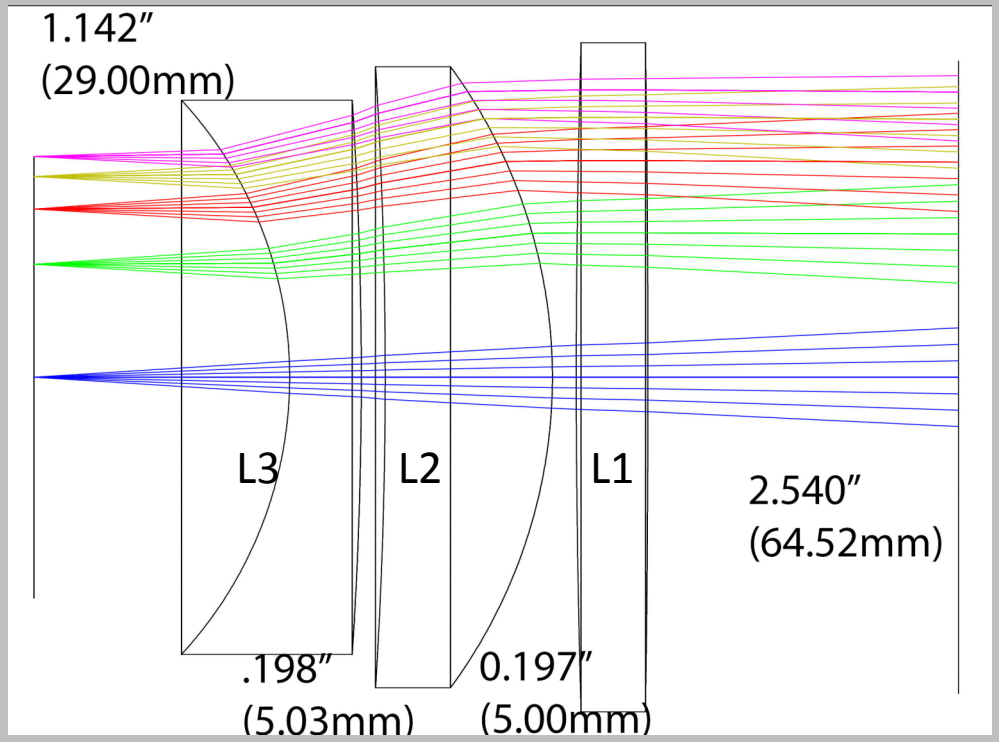
  - Plate Scale will be 0.111”/pixel

$$plate\_scale = \frac{206265 * 15.0 \mu m}{1000 * f/ * aperture(mm)} \frac{''}{pixel}$$



Layout

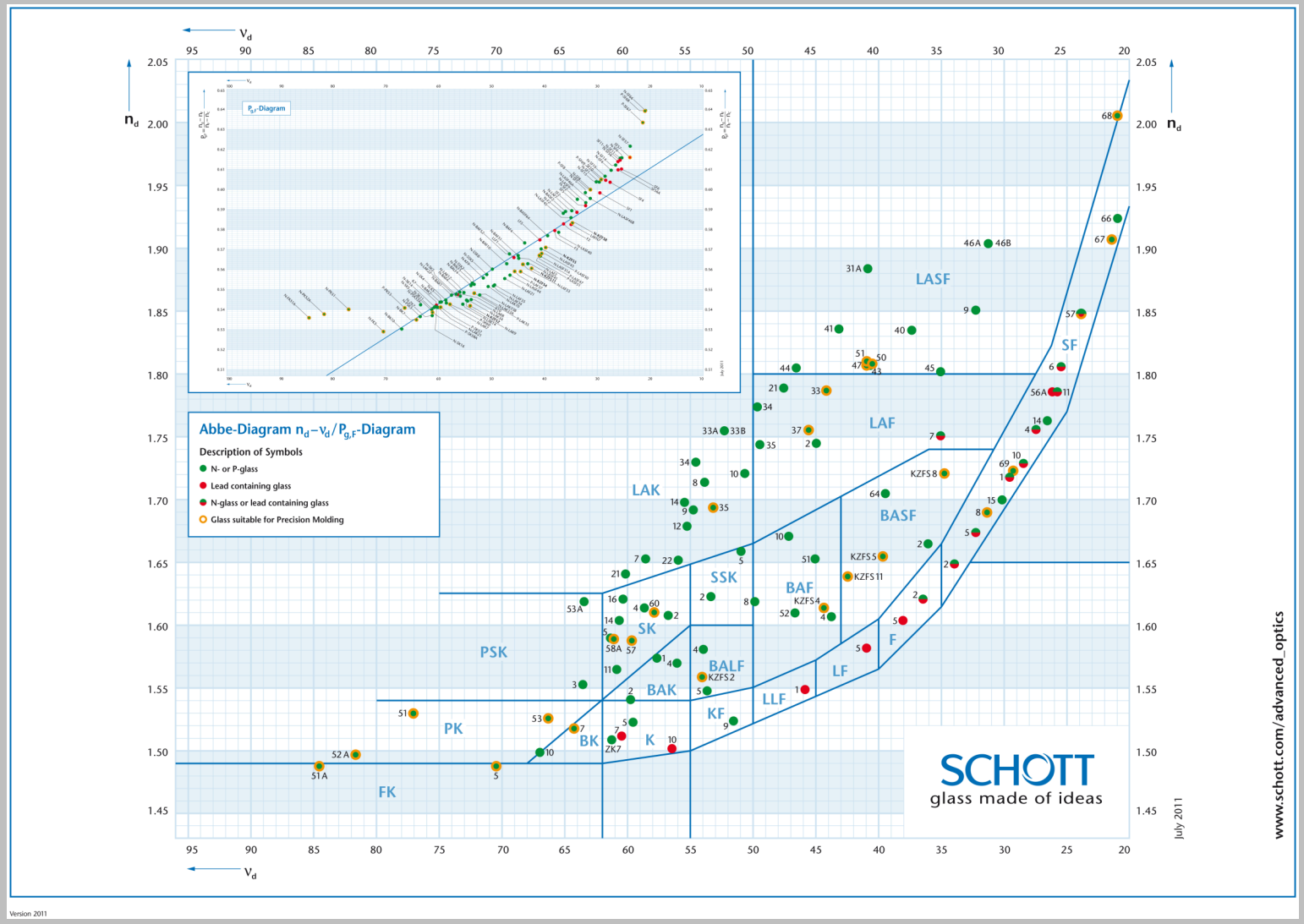
- Three element focal reducer
- Diameters with step added
  - L1 = 5.75”
  - L2 = 5.5”
  - L3 = 5.125”
- Glass types
  - L1 = SK16 (heavy crown)
  - L2 = SK14 (heavy crown)
  - L3 = F2 (flint glass)



Note: dimensions shown are minimum distance between optical surfaces (Z distance)

Crown Glass – low dispersion, low refractive index
Flint Glass – high dispersion, high refractive index

Glass Properties

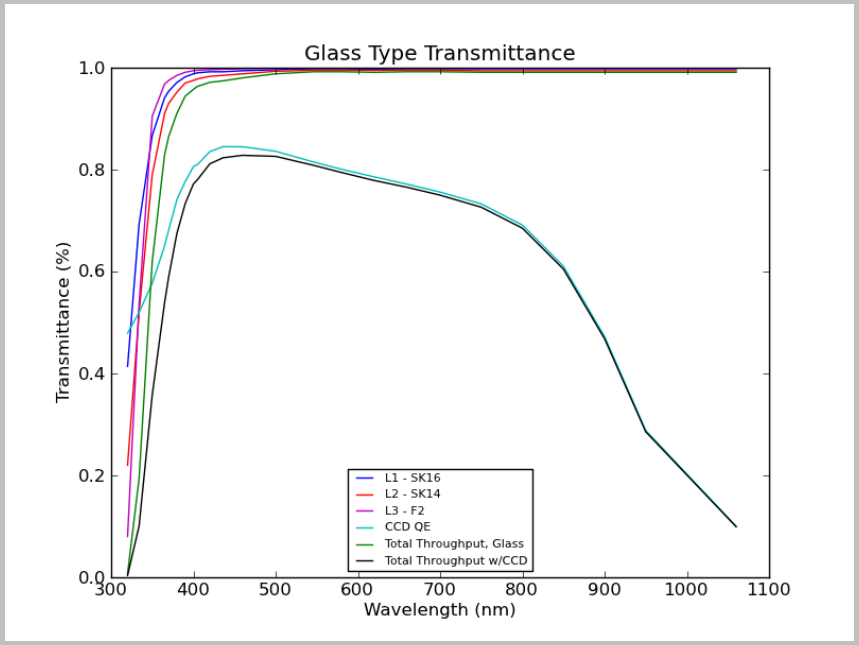


$$V_d = \frac{n_d - 1}{n_f - n_c}$$

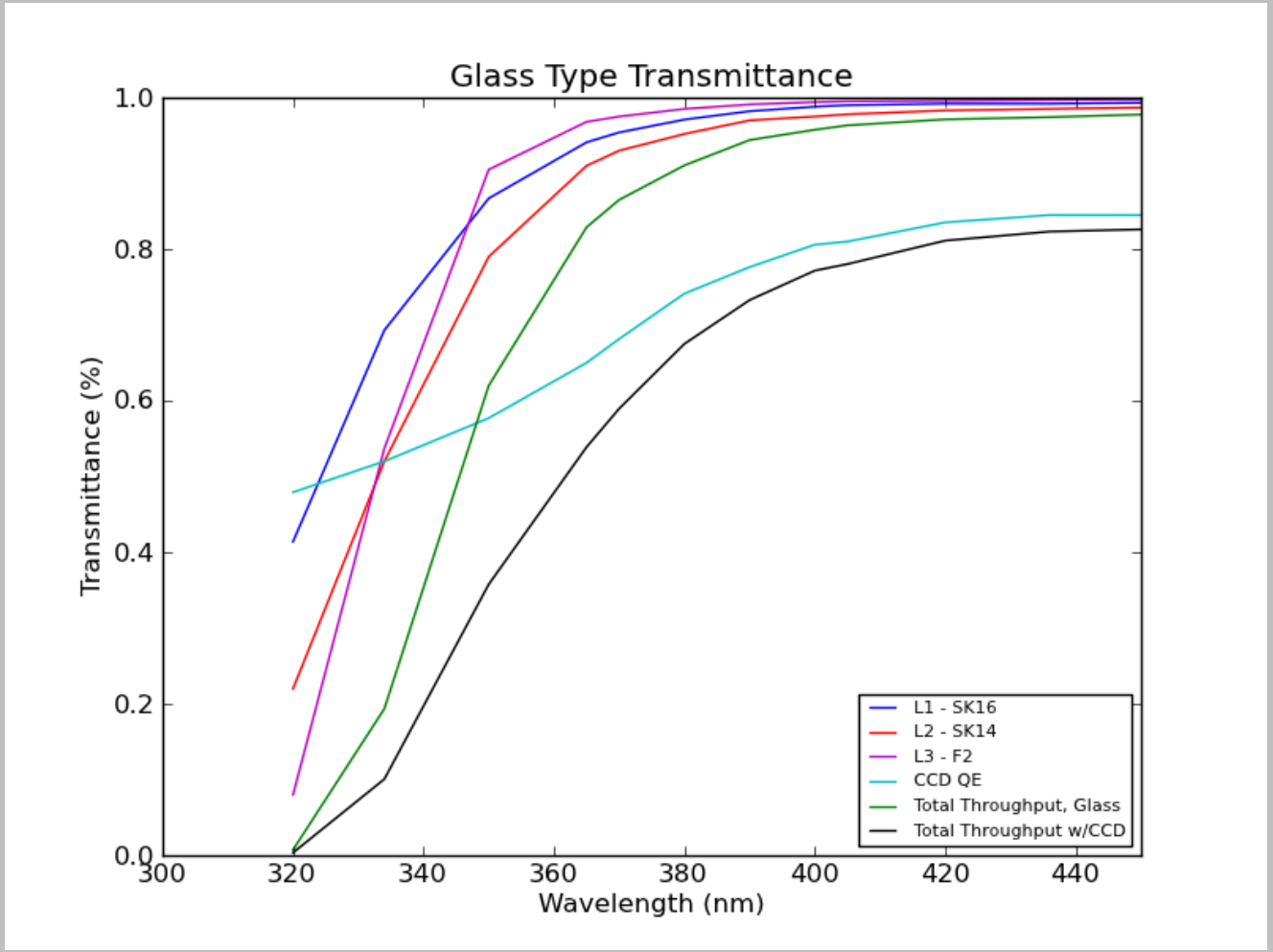
- V_d = Abbe Number is indicator of dispersion
- n_d = refractive index

Glass Selection

- Glass selection was performed by
  - creating a sub-catalog in Zemax with the selection criteria of good blue throughput and relative cost less than 2.5 * N-BK7
  - Hammer optimization performed to reduce merit function using glass substitution along with surface variables



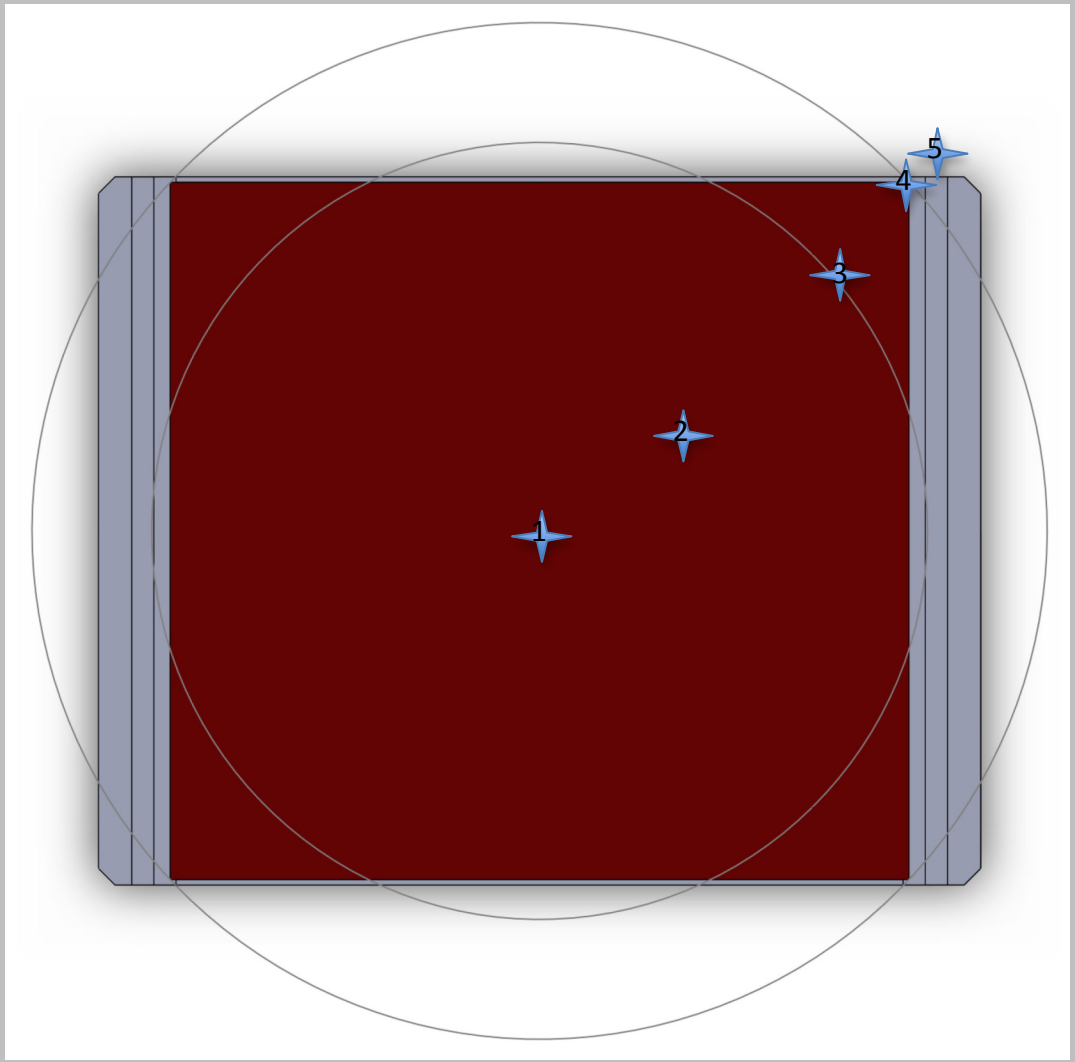
Glass Selection – Blue Performance



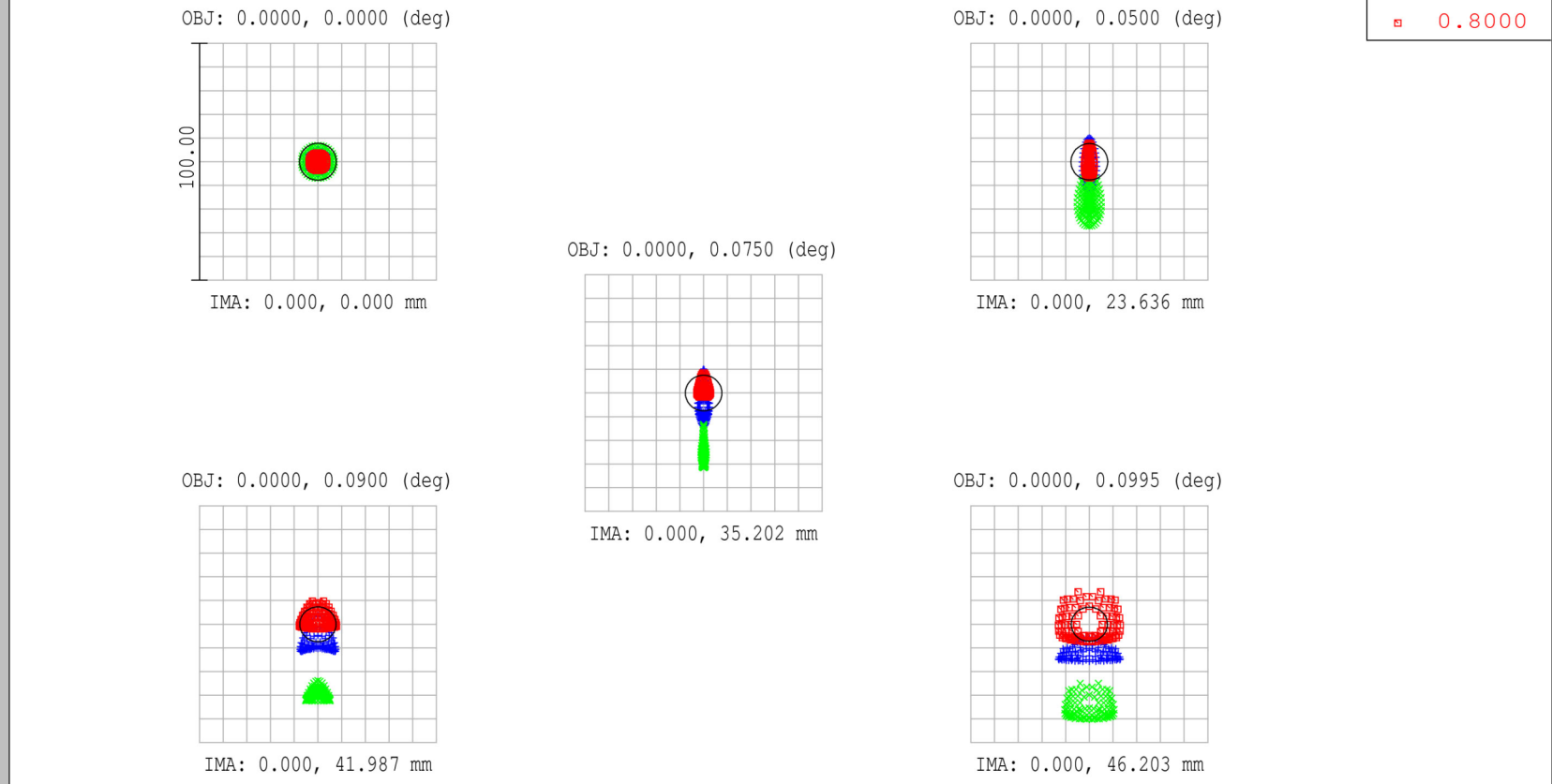
- Good response without using costly glass
- Response curves for internal transmission

Field

- Field positions sampled, in Zemax, overlayed on CCD
  - 1 = 0 deg
  - 2 = 0.05 deg (3’)
  - 3 = 0.075 deg (4.5’)
  - 4 = 0.09 deg (5.4’)
  - 5 = 0.0995 deg (5.97’)
- Radial maximum fields
  - Top edge of CCD = 3.79’
  - Right Edge of CCD = 3.80’
  - Diagonal Edge = 5.37’



Optical Performance



Spot Diagram

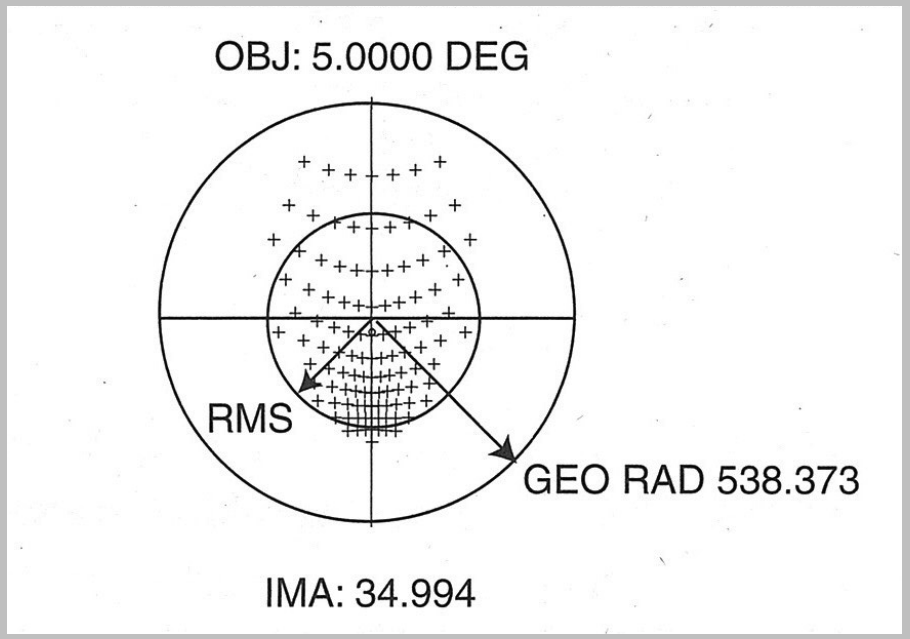
APO 3.5-m
10/11/2013 Units are µm. Airy Radius: 7.806 µm

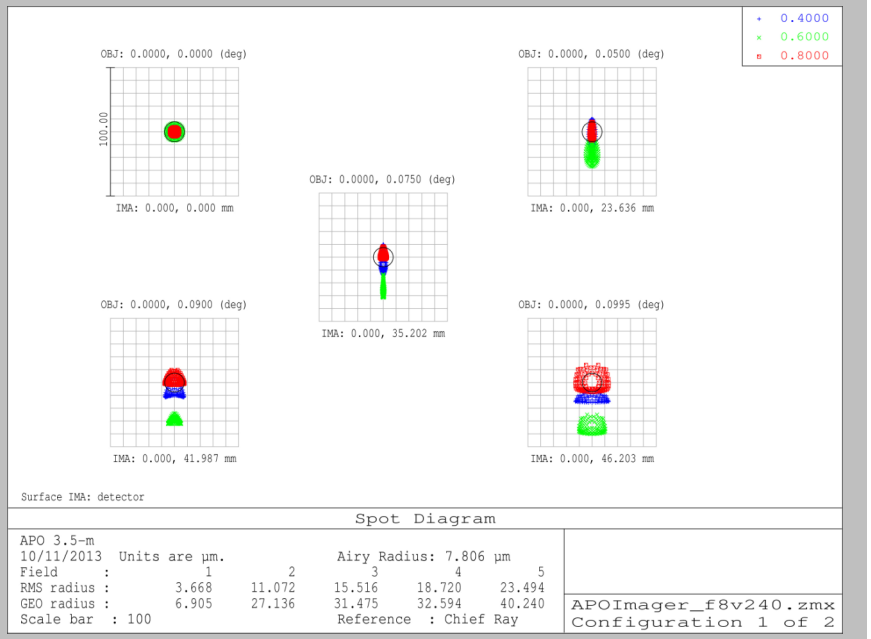
Field	1	2	3	4	5
RMS radius :	3.668	11.072	15.516	18.720	23.494
GEO radius :	6.905	27.136	31.475	32.594	40.240

Scale bar : 100 Reference : Chief Ray

APOImager_f8v240.zmx
Configuration 1 of 2

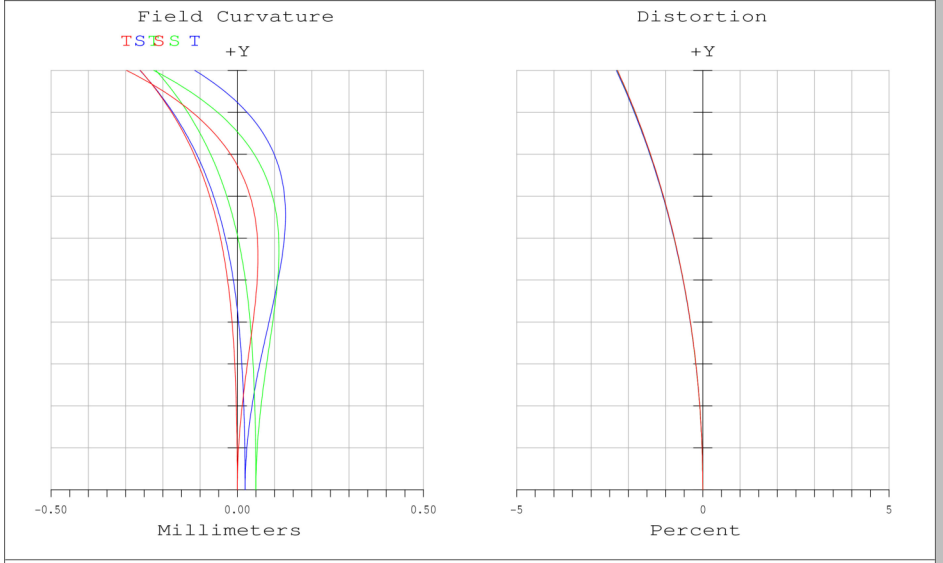
Optical Performance





- What does the spot size mean?
- The RMS radius is the most functional number for most observers
- Geometric radius is very important for astrometric calculations
- How do these numbers relate to the real world
  - If seeing is 0.6” then to be properly sampled the spot radius needs to be 20µm
  - If seeing is 1.0” then the spot radius needs to be 30µm

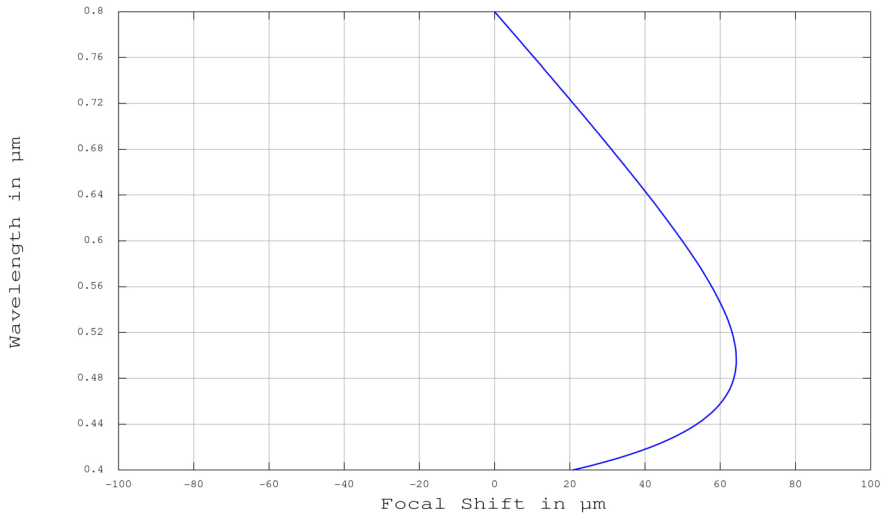
Performance



Field Curvature / F-Tan(Theta) Distortion

APO 3.5-m
10/11/2013
Maximum Field is 0.100 Degrees.
Wavelengths: 0.400 0.600 0.800

APOImager_f8v240.zmx
Configuration 1 of 2



Chromatic Focal Shift

APO 3.5-m
10/11/2013
Maximum Focal Shift Range: 64.2983 µm
Diffraction Limited Range: 204.685 µm
Pupil Zone: 0.0000

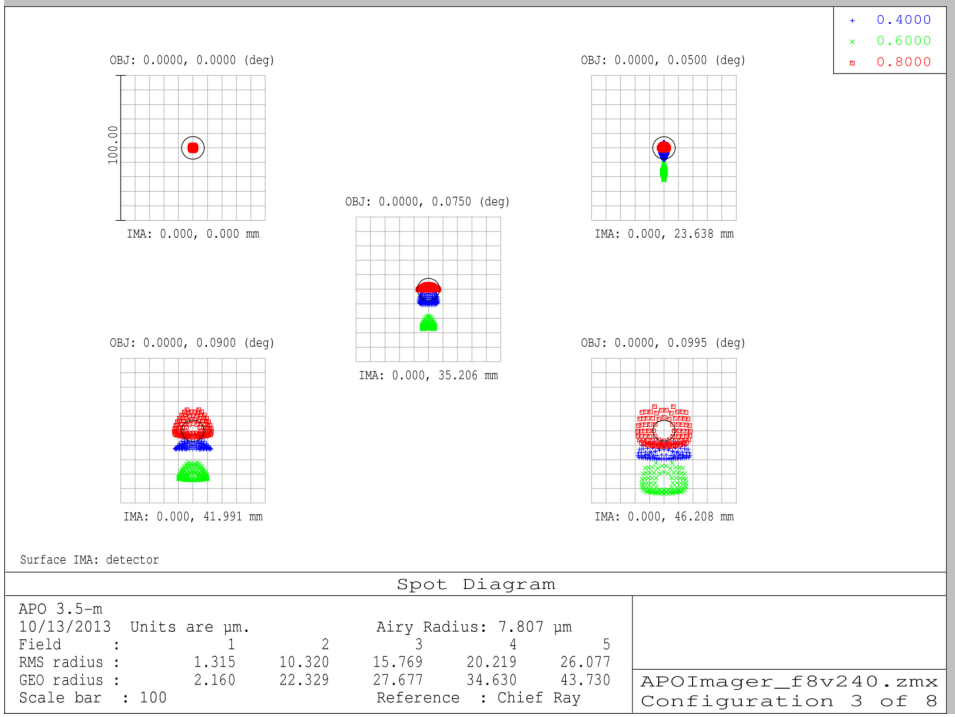
APOImager_f8v240.zmx
Configuration 1 of 2

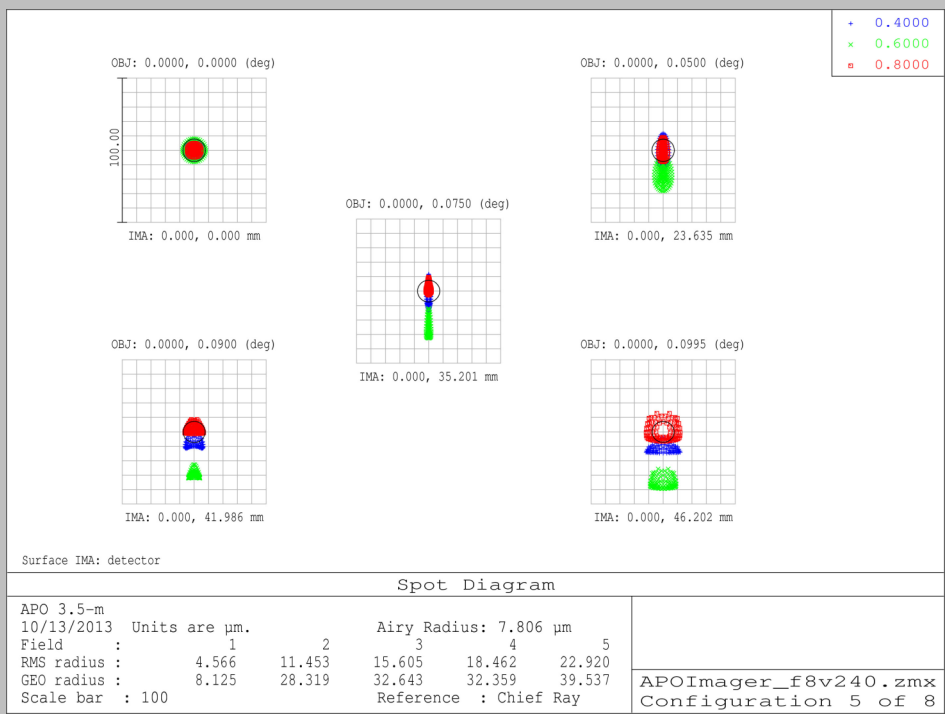
Ghost

- Ghosting optimization performed after good optical performance reached
- Ghost Pupil
  - Nearest ghost pupil located 11.1mm from CCD
  - Created off the back surface of L3 and the CCD
- Ghost Focus
  - Nearest ghost focus 13.7mm from CCD
  - Created off the back surface of L2 and the front surface of L3
- Optimal ghosting should be pushed to 18mm
- Need to perform Non-Sequential Mode Analysis to determine ghosting intensity

Thermal Modeling

- Temperature Ranges from -20C to +30C
- Temperature swings of up to 5C/hr
- Temperature changes modeled in Zemax, with spacers
- Left plot = -20C, Right plot = +30C
- Improvements seen towards center of CCD in the cold
- Improvements seen towards out edges of the CCD in warm
- Minor degradation in seeing on outer edge



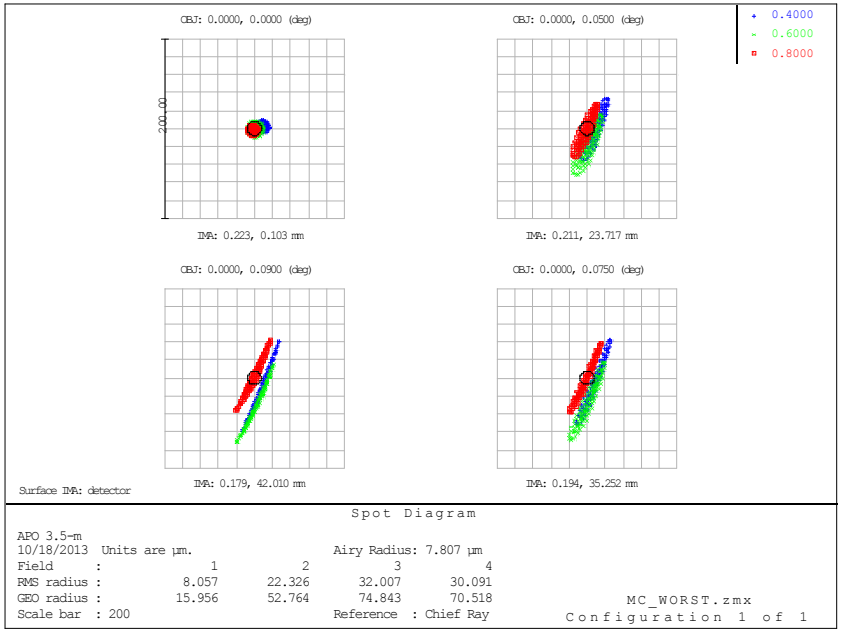


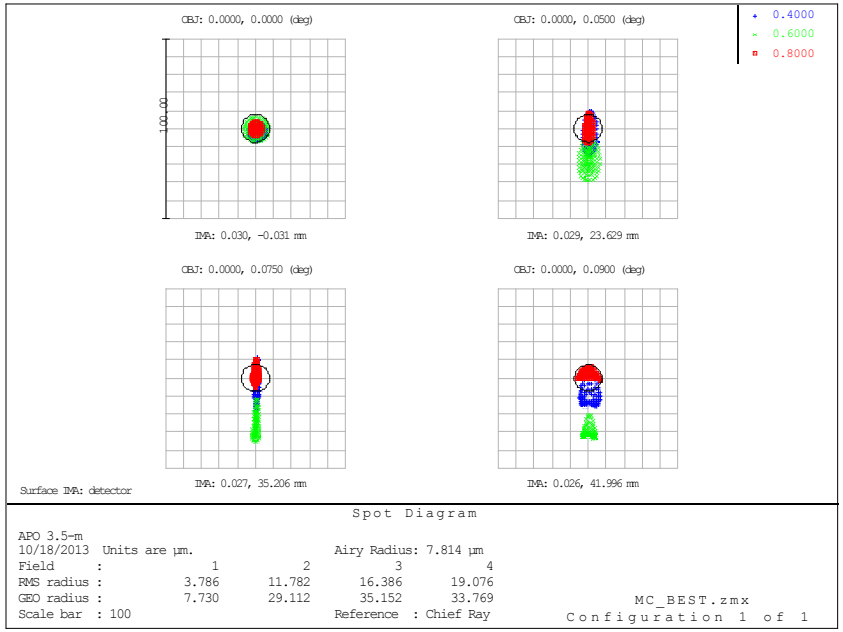
Tolerance

- Tolerancing introduces perturbations into the optical system to determine the degradation of the performance
- Surface tolerances initially set to +/-0.2mm for radius, thickness, tilt, and surface irregularities
- Element tolerance set to +/-0.2mm
- Inverse Sensitivity
  - What are the parameter ranges given the maximum allowed change in performance
  - Tilt of L2 and L3 found to be the worst ‘offenders’, but still found to be acceptable
- Sensitivity
  - What is the change in performance per set tolerance

Simulation Results

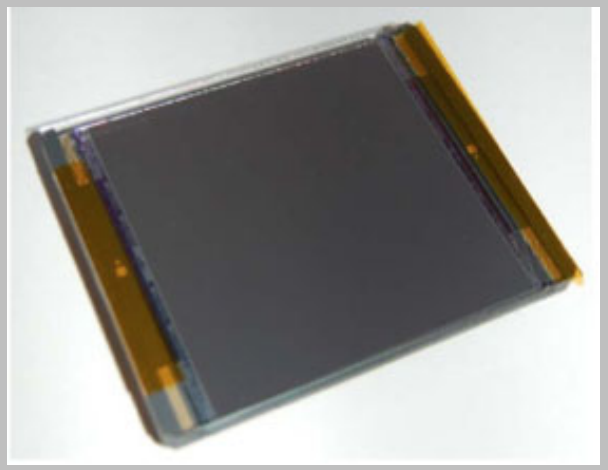
- Monte Carlo simulations run on tolerancing parameters
- 41 tolerancing variables
- 100,000 simulations run

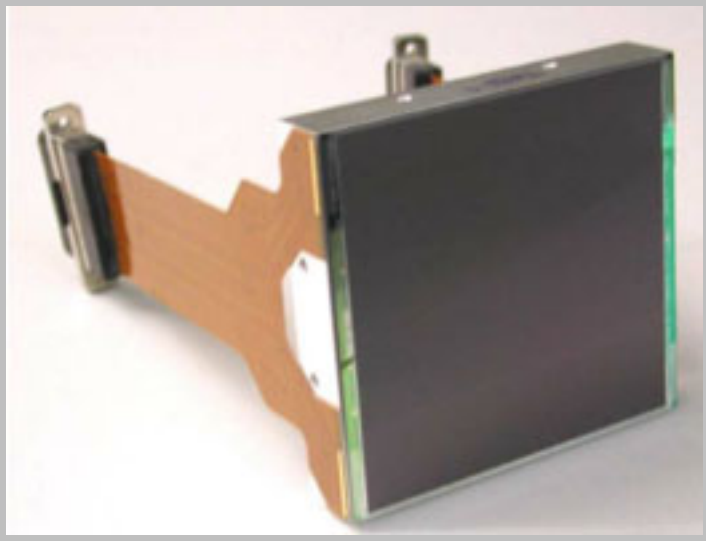




CCD

- E2V CCD 231-84
- 4K x 4K
- 15 micron pixels
- 61.4mm^2 imaging area
- Deep Depletion
- Ceramic Packaging





CCD Performance Comparison

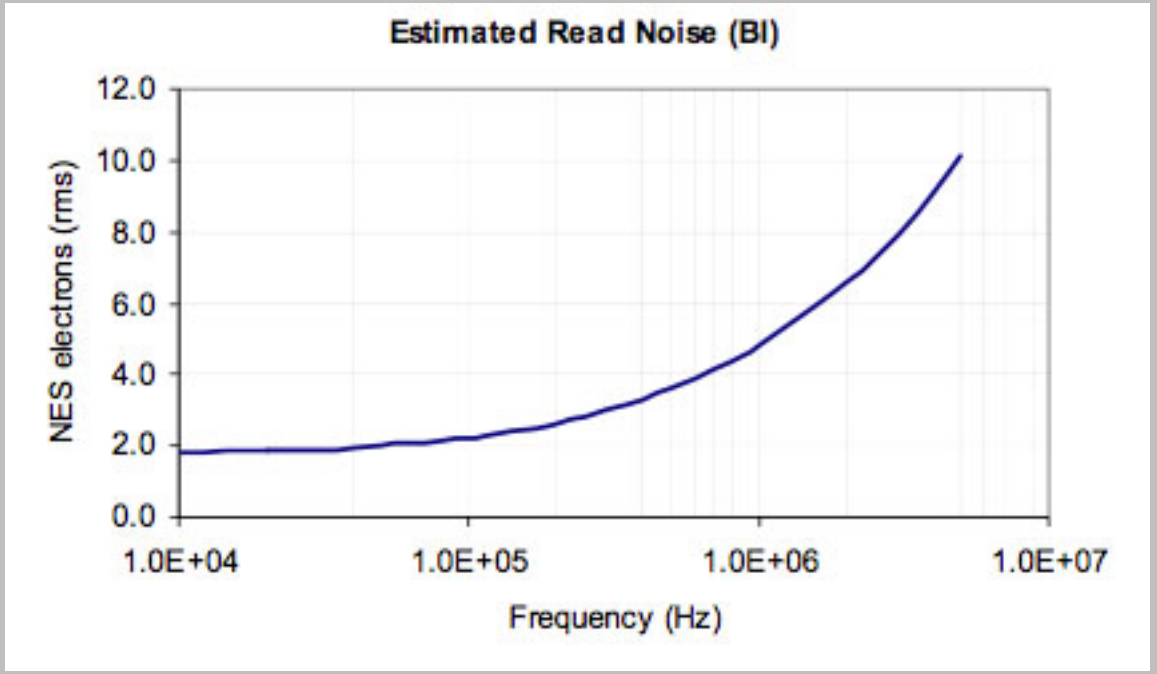
Table 2:: CCD Comparison

Spec	SPICam	CCD231
Pixel Size	$24\mu m$	$15\mu m$
Imaging Area	$49.1mm^2$	$61.4mm^2$
Read Noise	$5.7e^-$	$2e^-$ - $5e^-$
Gain	$3.36e^-$/ADU	$2.6e^-$/ADU
Dark Current	$2.5e^-$/pixel/hour	$3e^-$/pixel/hour
Readout Rate	35kHz	1MHz - 50kHz
Readout Time	120 seconds	4.2 - 84 seconds

Notes. Readout Rate and Time only based on 1x1 binning.

- The above table shows the differences between the selected E2V CCD231-84 and SPICam
- Improvements are seen across the performance spectrum

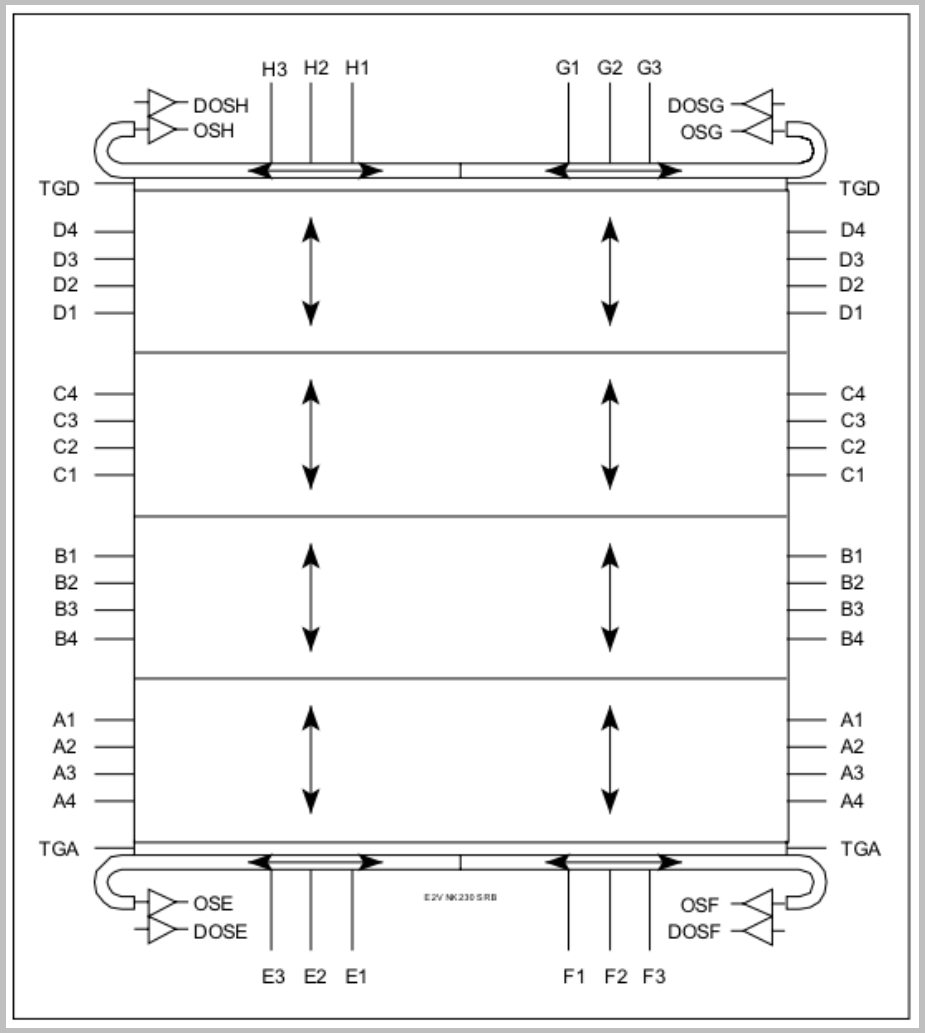
CCD Architecture



- Quad amplifier Readout
- Three read modes available (user selectable)
  - 900 KHz
    - 5 seconds readout (1x1 binning)
    - 5 electrons read noise
  - 400 KHz
    - 10 seconds (1x1 binning)
    - 3 electrons read noise
  - 100 KHz
    - 40 seconds (1x1 binning)
    - 2 electrons read noise

Readout Types

- Typical mode will use all 4 amplifiers to read out the entire chip
- User selectable command available to readout Upper two or Lower two sections independently
  - C & D clocked together
  - A & B clocked together
  - While clocking each half the other remain static
  - Possible uses include on chip guider and mosaic'ed filters

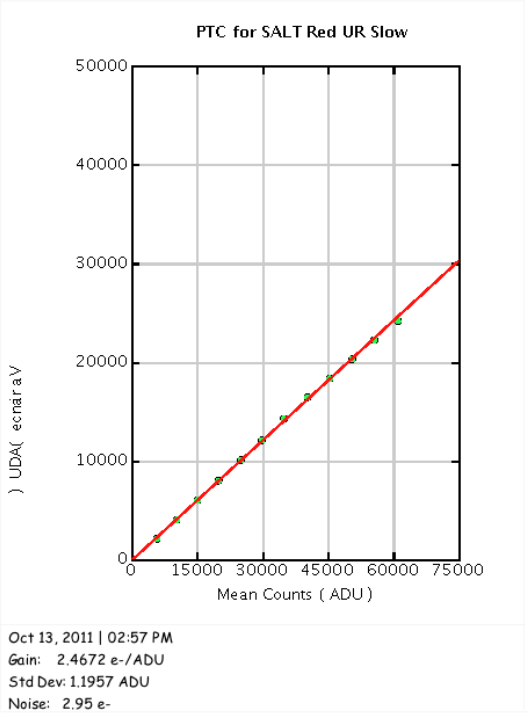


CCD Real World Examples

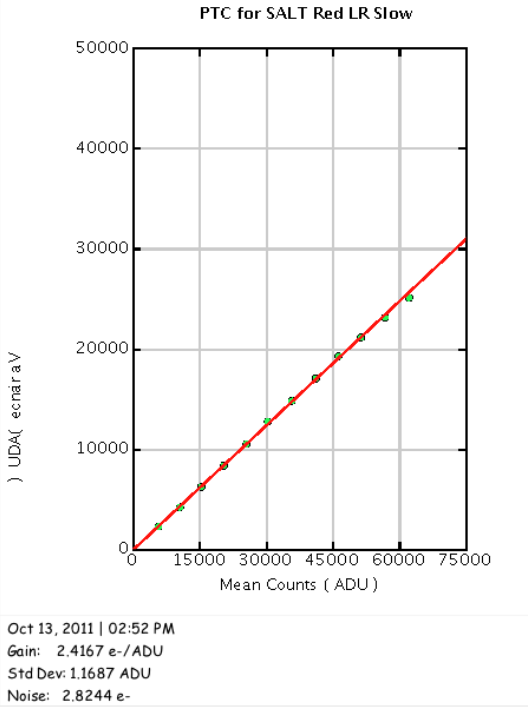
Plots are lab results of a CCD231-84 detector using Leach electronics

Left: 50KHz readout
Right: 1MHz readout

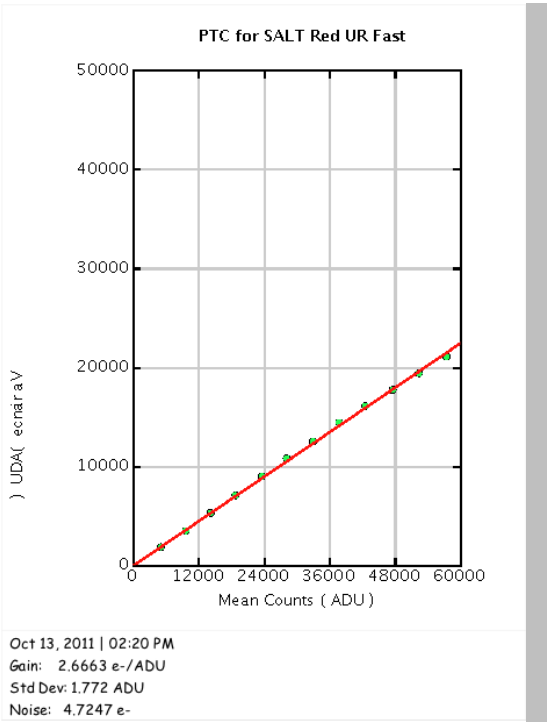
Noise results close to E2V expected numbers



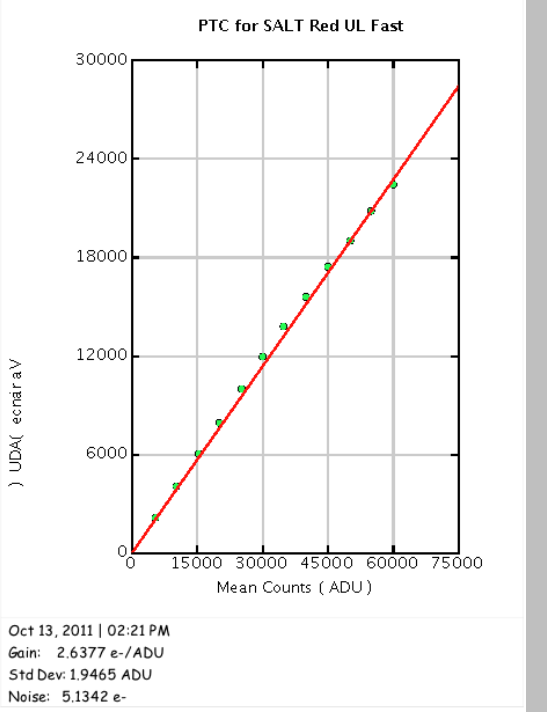
Oct 13, 2011 | 02:57 PM
Gain: 2.4672 e-/ADU
Std Dev: 1.1957 ADU
Noise: 2.95 e-



Oct 13, 2011 | 02:52 PM
Gain: 2.4167 e-/ADU
Std Dev: 1.1687 ADU
Noise: 2.8244 e-

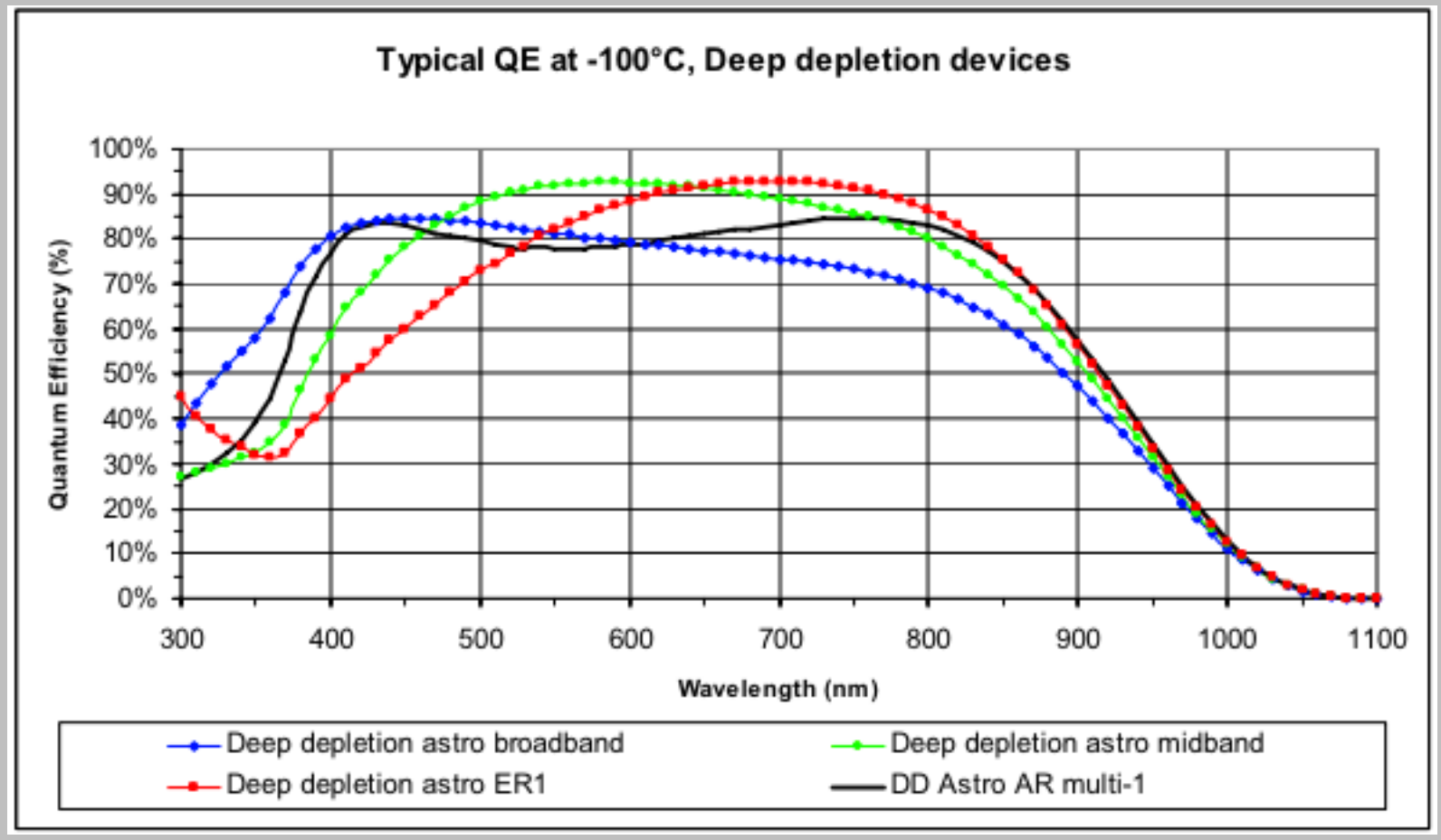


Oct 13, 2011 | 02:20 PM
Gain: 2.6663 e-/ADU
Std Dev: 1.772 ADU
Noise: 4.7247 e-



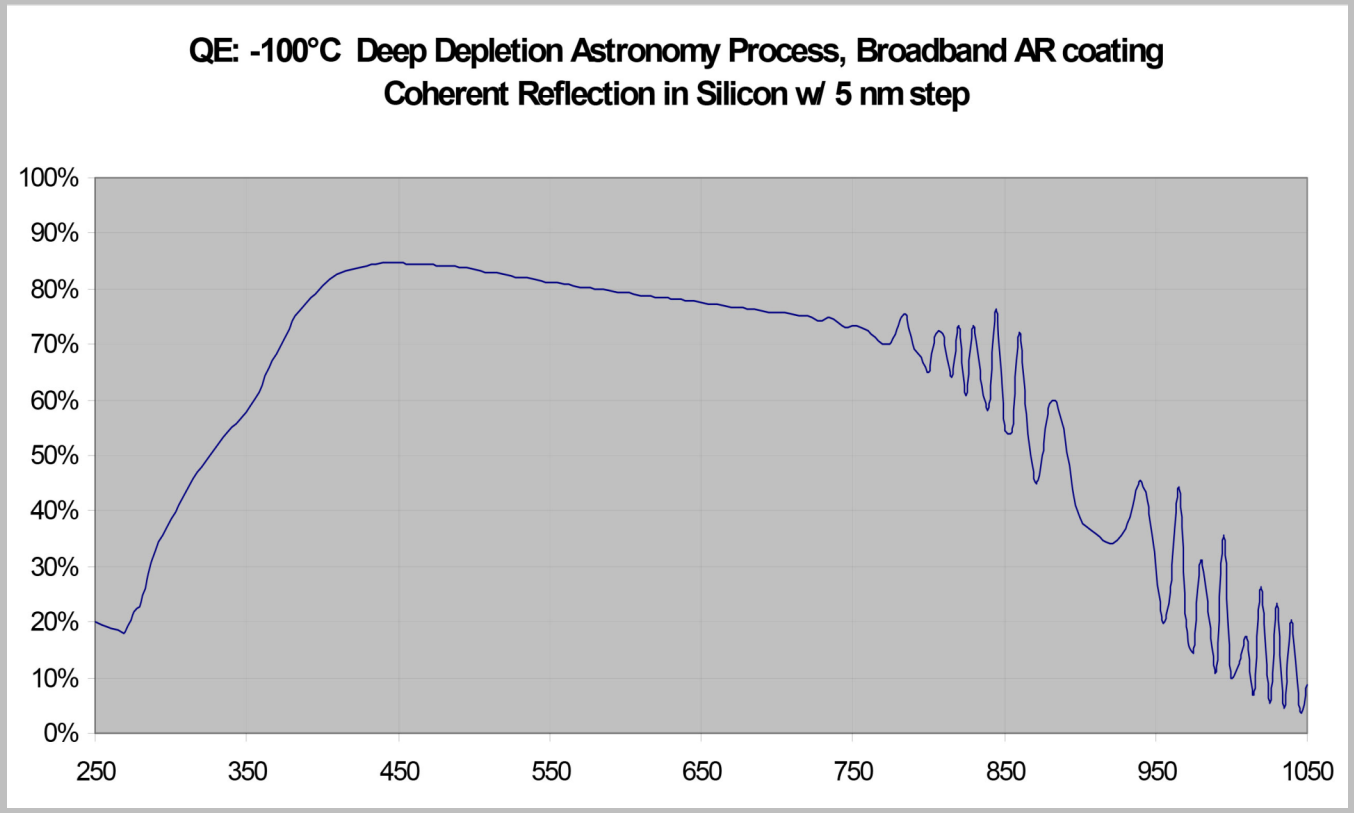
Oct 13, 2011 | 02:21 PM
Gain: 2.6377 e-/ADU
Std Dev: 1.9465 ADU
Noise: 5.1342 e-

Quantum Efficiency



- Range of coatings shown above
- Expected to go with the Astro Broadband (blue curve)

Fringing



- Plot of deep depletion fringing for CCD231
- Optional fringe suppression option to decrease fringing to 2%