Keck I Cassegrain ADC: Preliminary Design Overview

UCO/Lick Observatory

15 October 2003

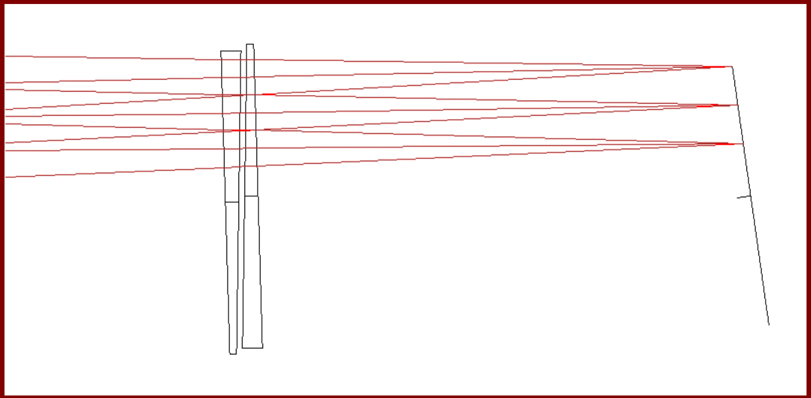
Outline

- ADC conceptual design
- Science Requirements
- Mechanical Design
- Electrical Design / Control Software
- Optical Design
- Optical Design Enhancements

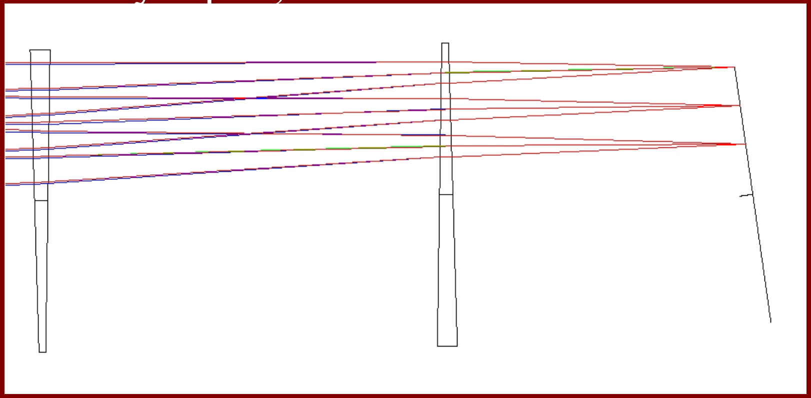
ADC Conceptual Design

- Linear ADC design
- Variable prism separation provides correction
- UV-to-near IR transmission requires fused silica optics

Nulled



Fully Open, Z=60°



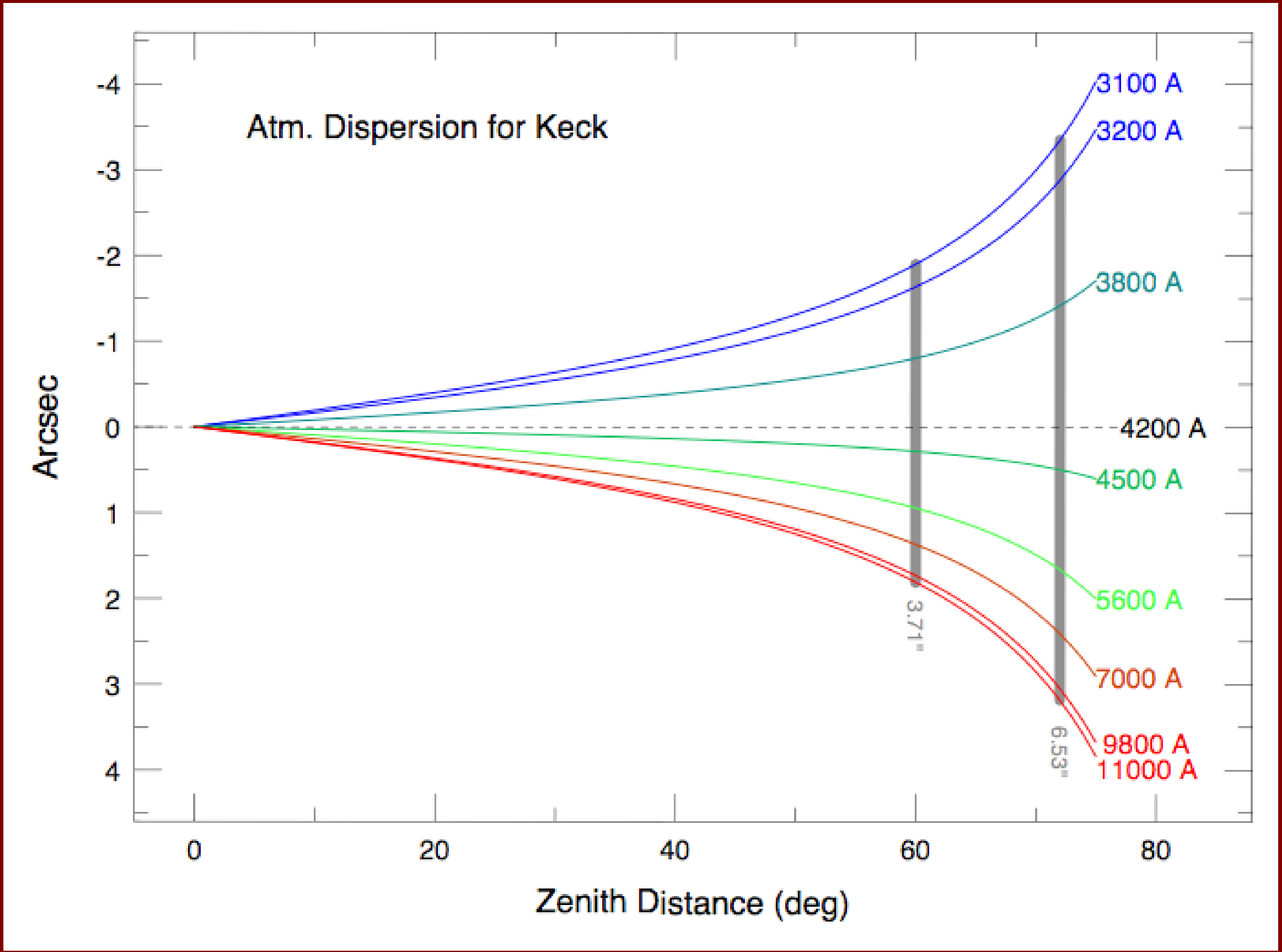
Science Requirements

- Set out in “Requirements Document”
- Good correction for atm. dispersion over

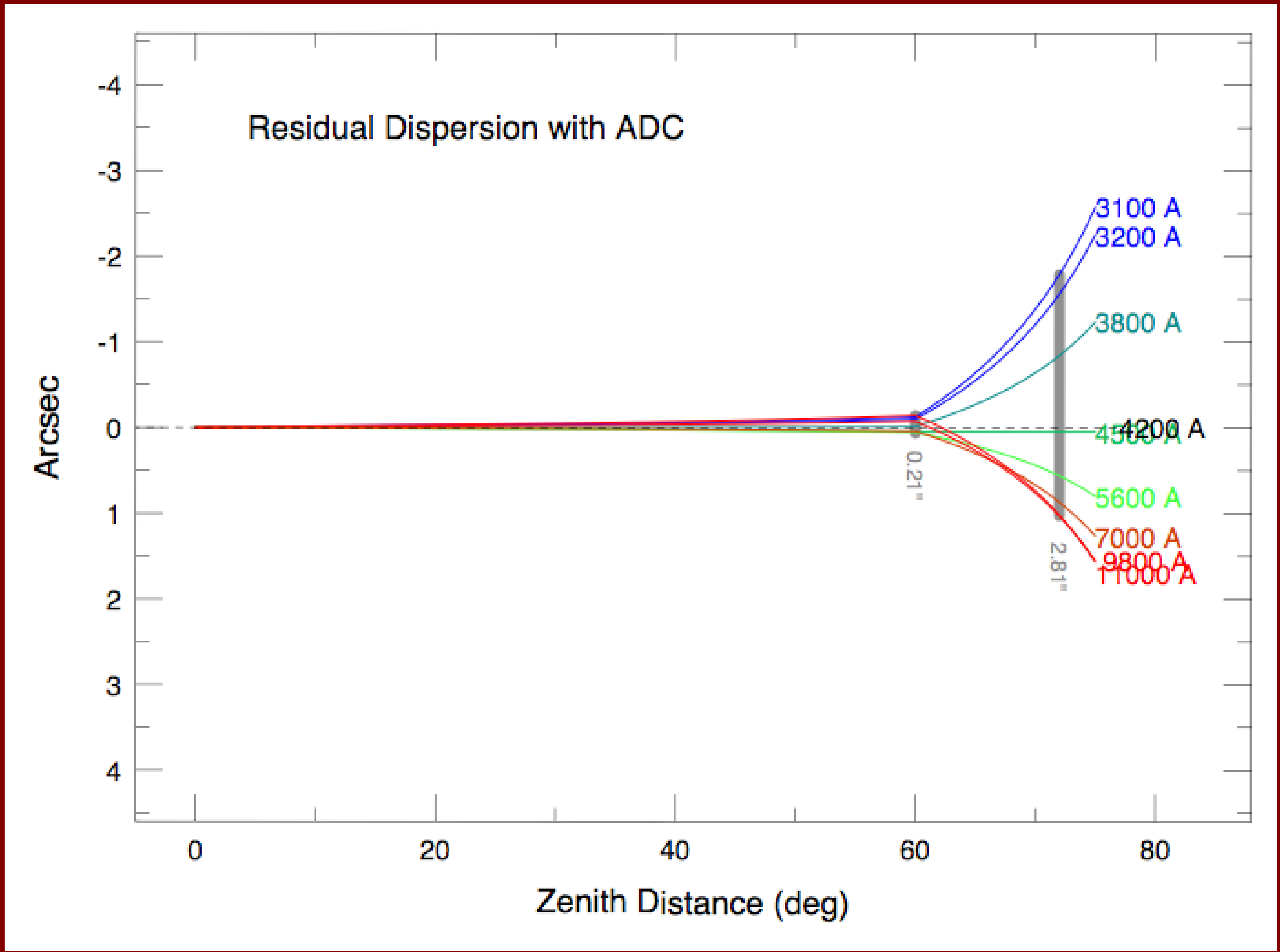
  --- 0.31 to 1.1μm in wavelength

  --- 0 to 60° Z (zenith distance)
- Low impact on image quality over 10-arcmin radius FOV
- Low impact on throughput (i.e. high transmission)

Uncorrected



Corrected with ADC



Low Impact on Image Quality

- ADC in "perfect" telescope
- Compare with actual astigmatism:
  - -- 85 μm deviation at 4-arcmin
  - -- 350 μm deviation at 10-arcmin

Description	*Prism tilt*	*Prism sep.*	*Max. image aberration*	*RMS radius*	*Dominant aberration*
No ADC	-	-	0	0	-
Closed, untilted ADC	0	0	0.5 *μm*	<0.2 *μm*	Spherical
Closed, opt-tilt ADC	1.67°	0	~3	~0.7	Lateral Coma
Closed, Design ADC	1.67°	20 mm	~6	~1.5	Lateral Coma
Fully Open, Design ADC	1.67°	1700 mm	~140	~38	Lateral Coma

Low Impact on Image Quality

- ADC with real system, at LRIS slitmask
- Nulled position results here
- Images at full-extension are 15-30% larger
- FWHM(″) ≈ 0.0023 R_{rms}(μm)

Field	No ADC	ADC nulled, 0.45-μm	ADC nulled, polychromatic *
1 (0°)	107 ± 50 μm	108 ± 50 μm	110 ± 50 μm
2 (45°)	″	108 ± 50	110 ± 50
3 (90°)	″	108 ± 50	109 ± 49
4 (135°)	″	107 ± 50	109 ± 49
5 (180°)	″	107 ± 49	108 ± 49

Low Impact on Image Quality

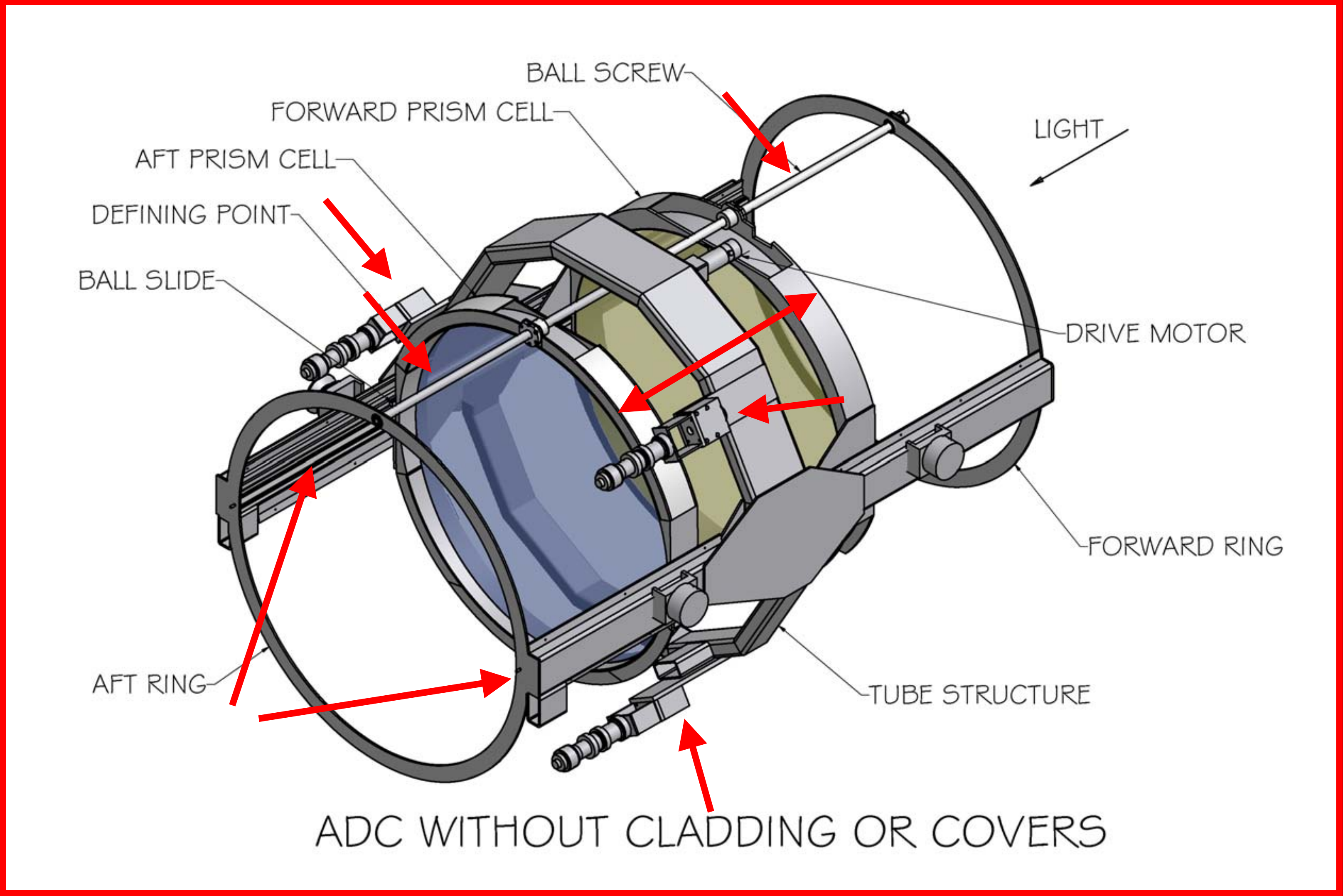
- ADC with real system, including LRIS

Camera	Field	No ADC	ADC nulled	ADC open
Blue*	2	$17.0 \pm 2.1\ \mu m$	$17.6 \pm 1.9\ \mu m$	$20.2 \pm 4.2\ \mu m$
Blue*	4	"	17.3 ± 2.1	18.0 ± 1.9
Red**	2	25.8 ± 6.6	26.1 ± 6.6	27.7 ± 6.3
Red**	4	"	25.9 ± 7.2	29.4 ± 7.7

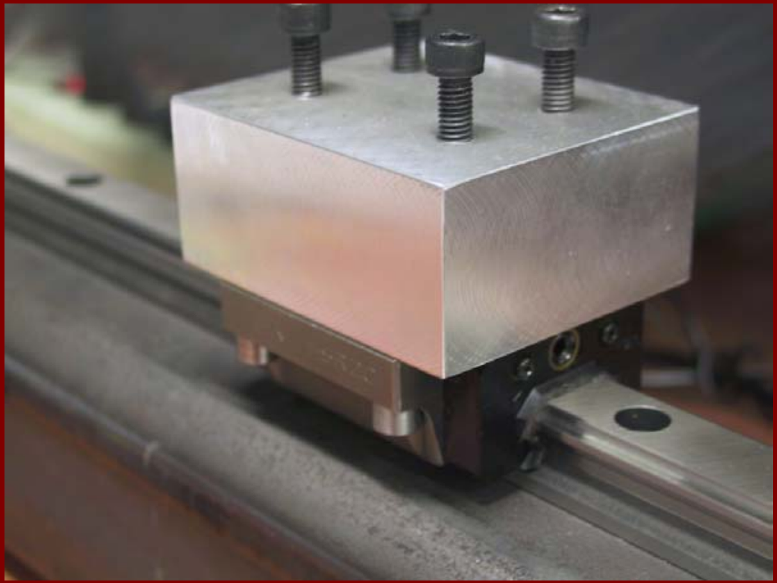
Mechanical Design

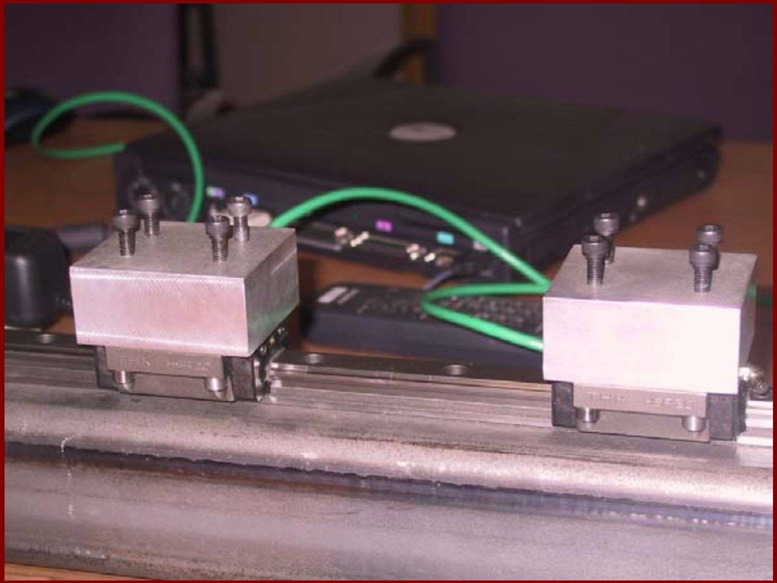
- Independent Module mounted in Tertiary Tower
- Prisms held rigidly by 2 linear bearings (2 bearing “cars” on each of two rails)
- Single stage: prism position controlled by single lead screw (lead screws are coupled)
- Prisms mounted in cells with 3 hard pads

Mechanical Design: Overview



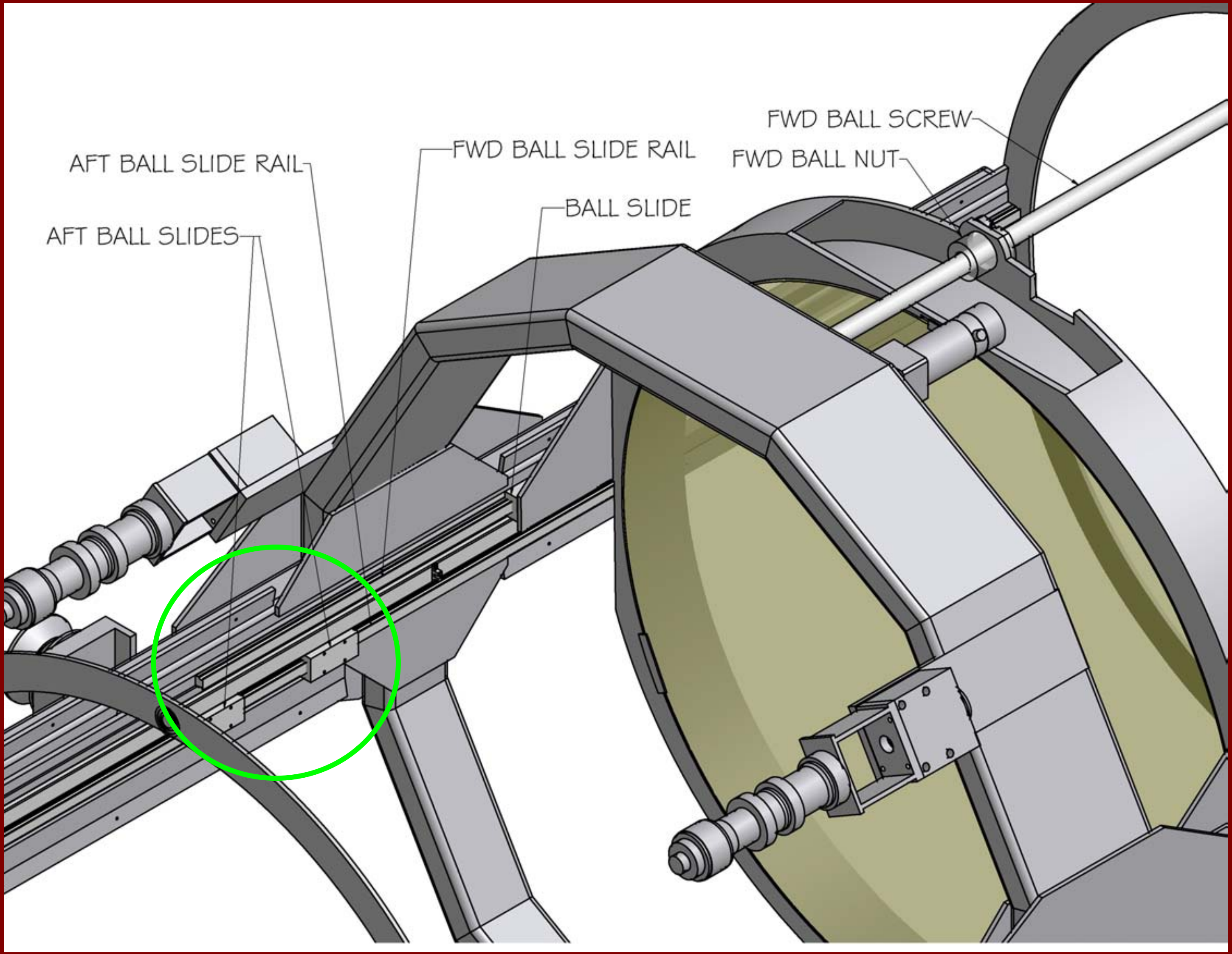
Linear Bearings (Ball Slides)



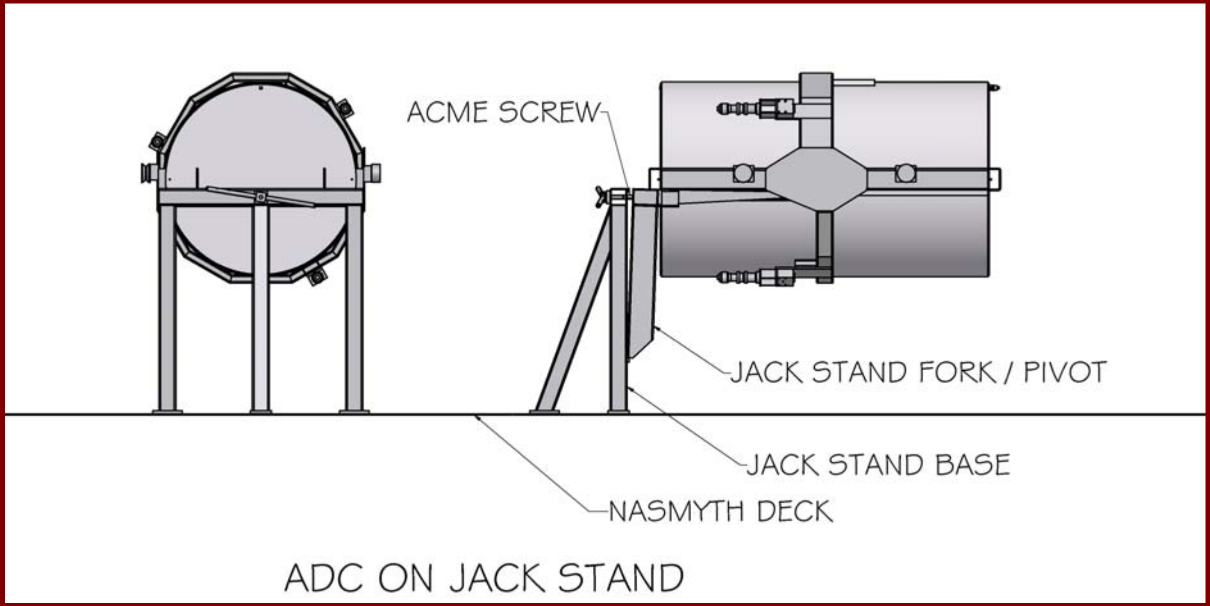


- (left) Single ball slide "car"
- (right) A pair of cars spaced 7.5-in apart provide the support on each side of the grating cell, and hold the angle of the cell precisely
- Each prism rides on its own pair of rails

Mechanical Design: Detail



Mechanical Design: Storage



- ADC module fits into transfer module for installation and removal
- Stores on permanently-mounted jack stand on Nasmyth deck

Mechanical Design

Preliminary Design Report includes:

- Design of ADC module
- FEA analysis of flexure (including optics)
- FEA analysis of natural frequencies
- Design of storage jack stand

Electronics

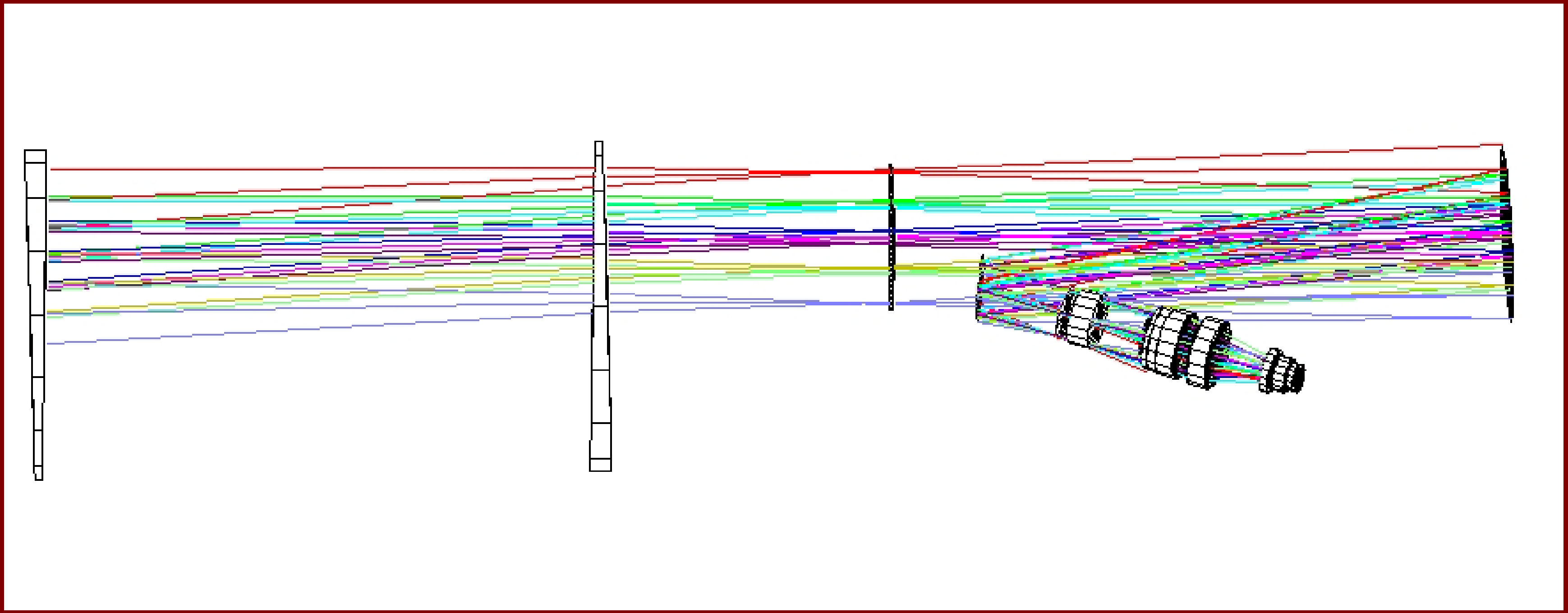
- Electronics for single stage are relatively simple
- Two specific components:
  - Stage motor and encoders (2) and limit switches in module
  - Electronics enclosure contains Galil controller, power supply, terminal server and hub
- Electronics enclosure is cooled and sits on Nasmyth platform (portable)

Control Software

- Control software for single stage is simple
- Prism separation set as function of elevation
  - must access DCS
  - “slow updates”
- Engineering GUI will be provided with OA and observer modes
- CARA will need to provide software changes to pointing model and focus algorithm

Optical Design

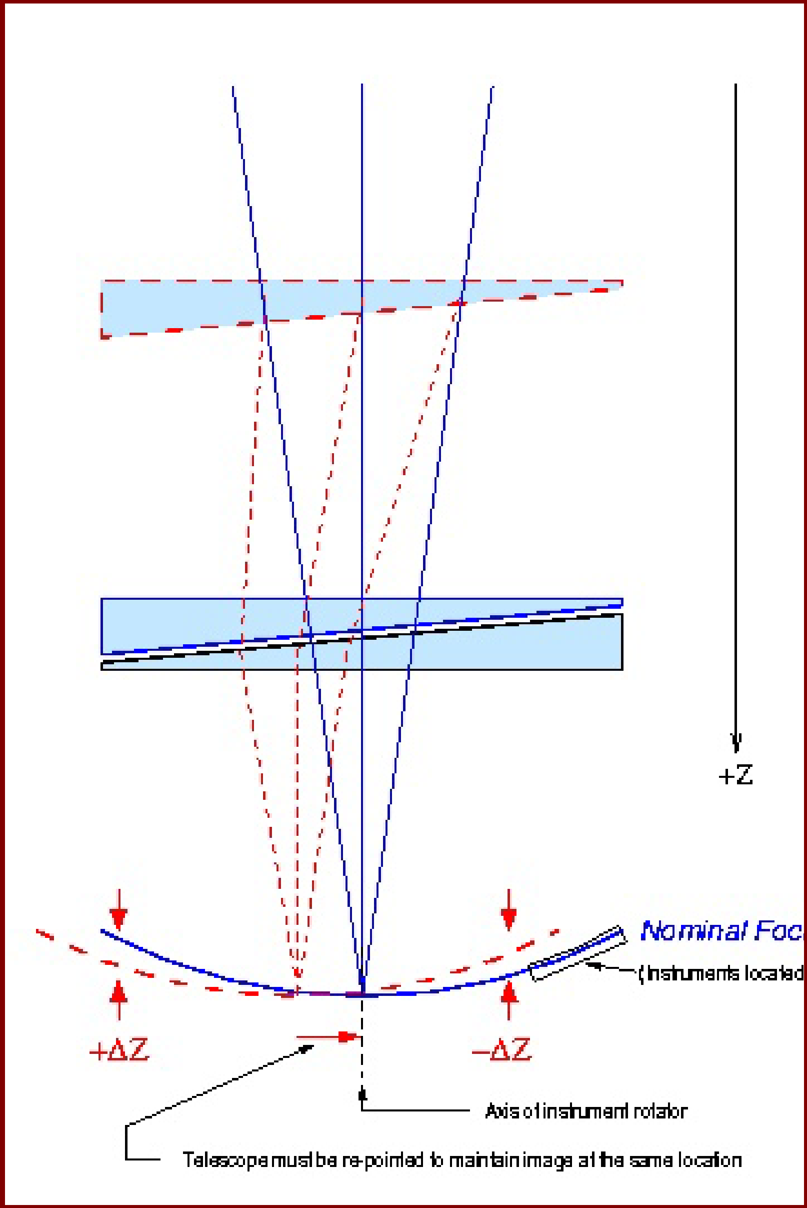
- Performed with ZEMAX
- Images analyzed at LRIS slitmask surface and LRIS (Red and Blue) focal surfaces



Linear ADC Effects

LADC displaces focus:

- Must repoint telescope
- Tilted focal surface -- must refocus telescope for prism separation and rotator angle
- Possible changes in vignetting
- Displaced pupil at grating (barely OK)
- Must oversize/displace prisms to minimize clear aperture



Optical Design

Optical Design Report (App. 2) includes:

- Native ADC aberrations
- Residual dispersion measurements
- Selection of best prism tilts wrt optical axis
- Image quality results at LRIS slitmask (for spectroscopy) and LRIS (red and blue) CCDs
- Distortion (not a problem)
- Transmission estimates
- Discussion of ghosts
- Tolerances (alignment, sag, index inhomogeneity)
- Guider vignetting (<30% over 7% of field)

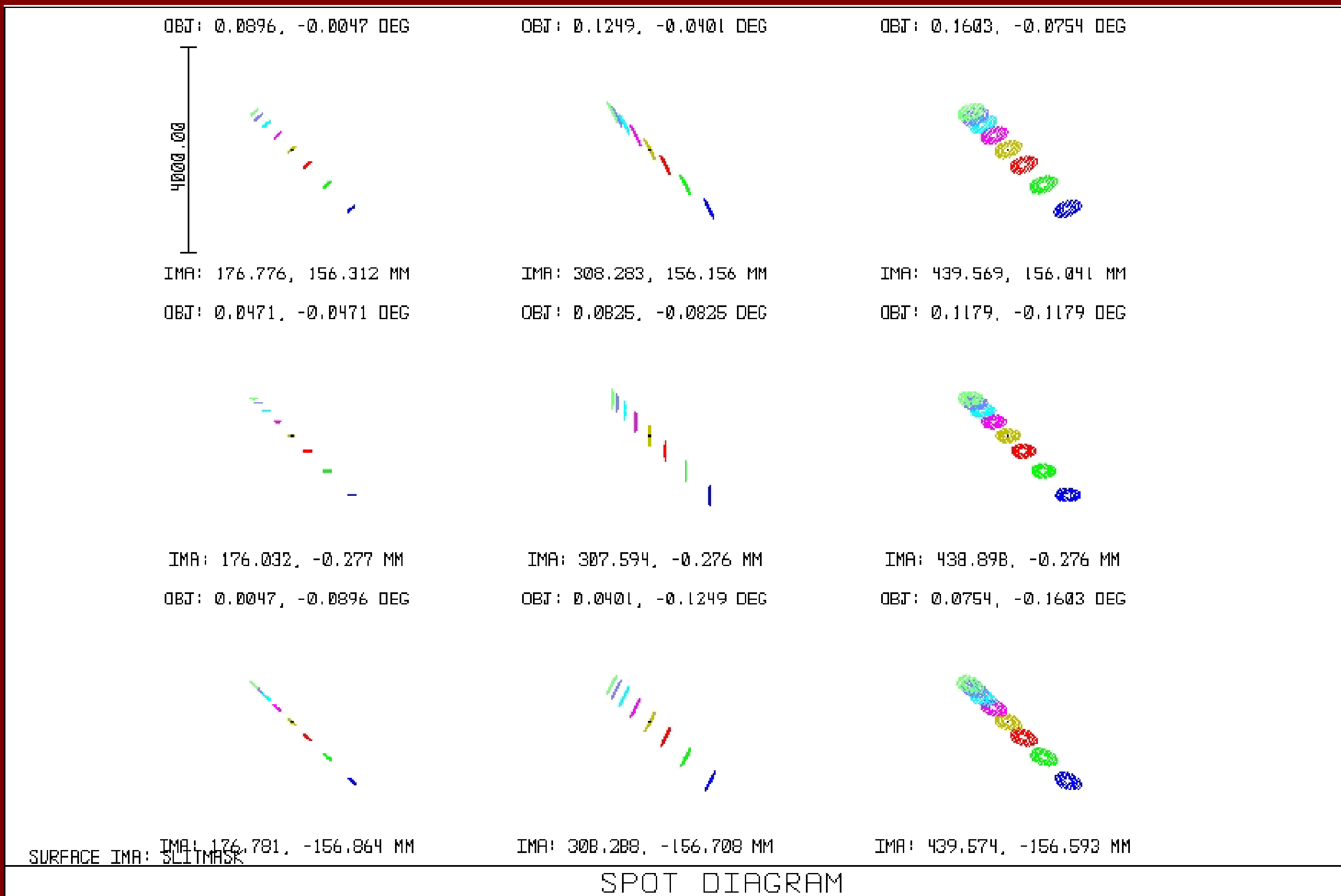
Optical Design Parameters

Prism opening angle	2.5°
Prism central thickness	45 mm
Prism clear aperture	1022.2 mm (min.) + 10 mm for safety
First prism offset	-22.1 mm (below center)
Minimum prism edge thickness	22 mm
First prism angle at outer surface	1.67°
First prism angle at inner surface	-0.83°
Minimum prism separation	20 mm
Maximum prism separation	1700 mm
Location in front of telescope focal surface	1695 mm – center of ADC 800 mm – min. distance (wrt 2^{nd} prism)
Zenith distance for full correction	0 -- 60°
Prism Material	Fused Silica (Grade D suggested)
Coatings	MgF_2 + Sol-Gel
Expected Transmission	> 94%

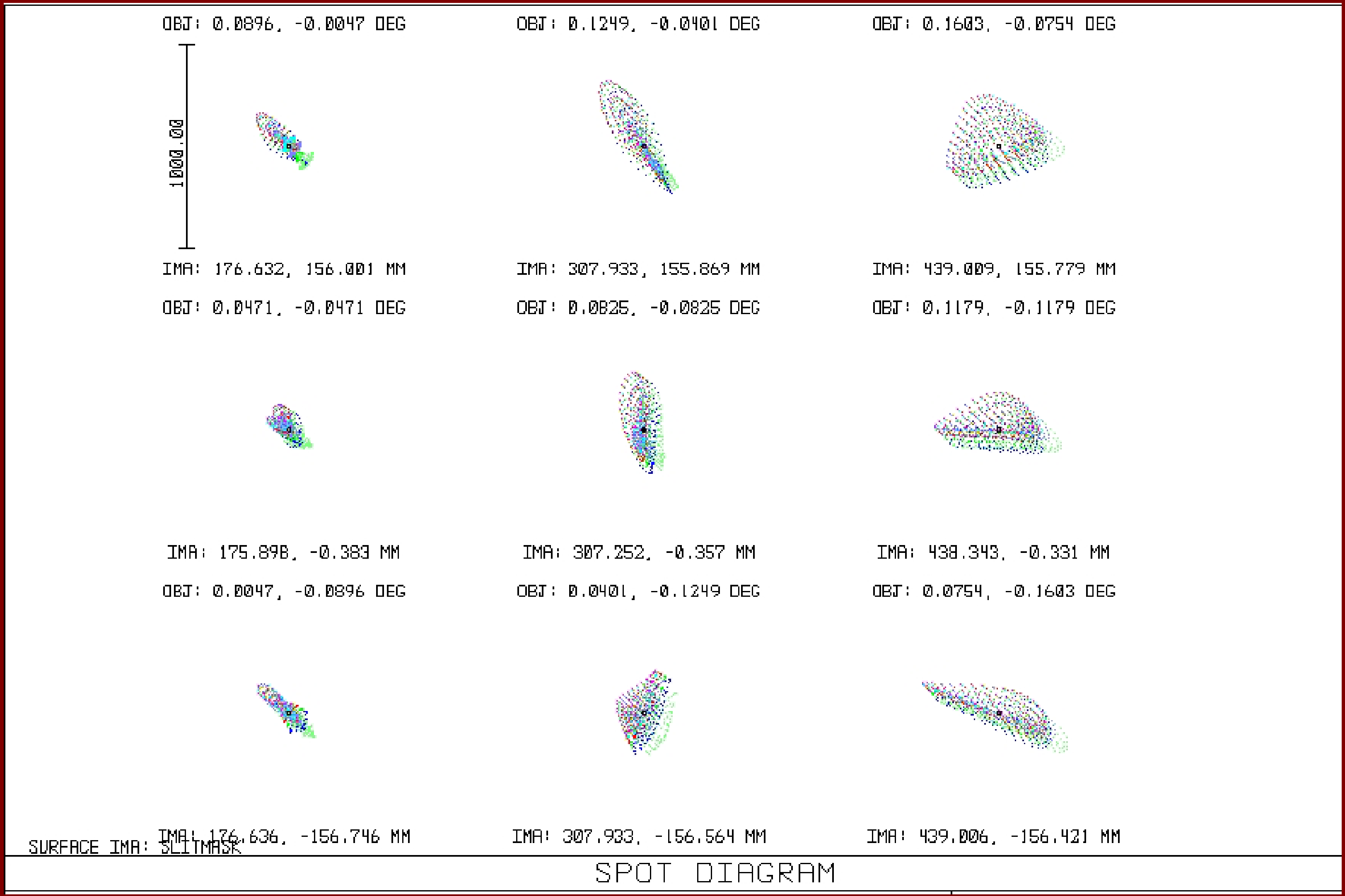
Optical Design Tolerances

Tolerance in prism position, axial	10 mm
Tolerance in prism position, radial	<5mm (set by safety margin above)
Tolerance in prism angle	0.2°
Tolerance in index inhomogeneity	3×10^{-5}

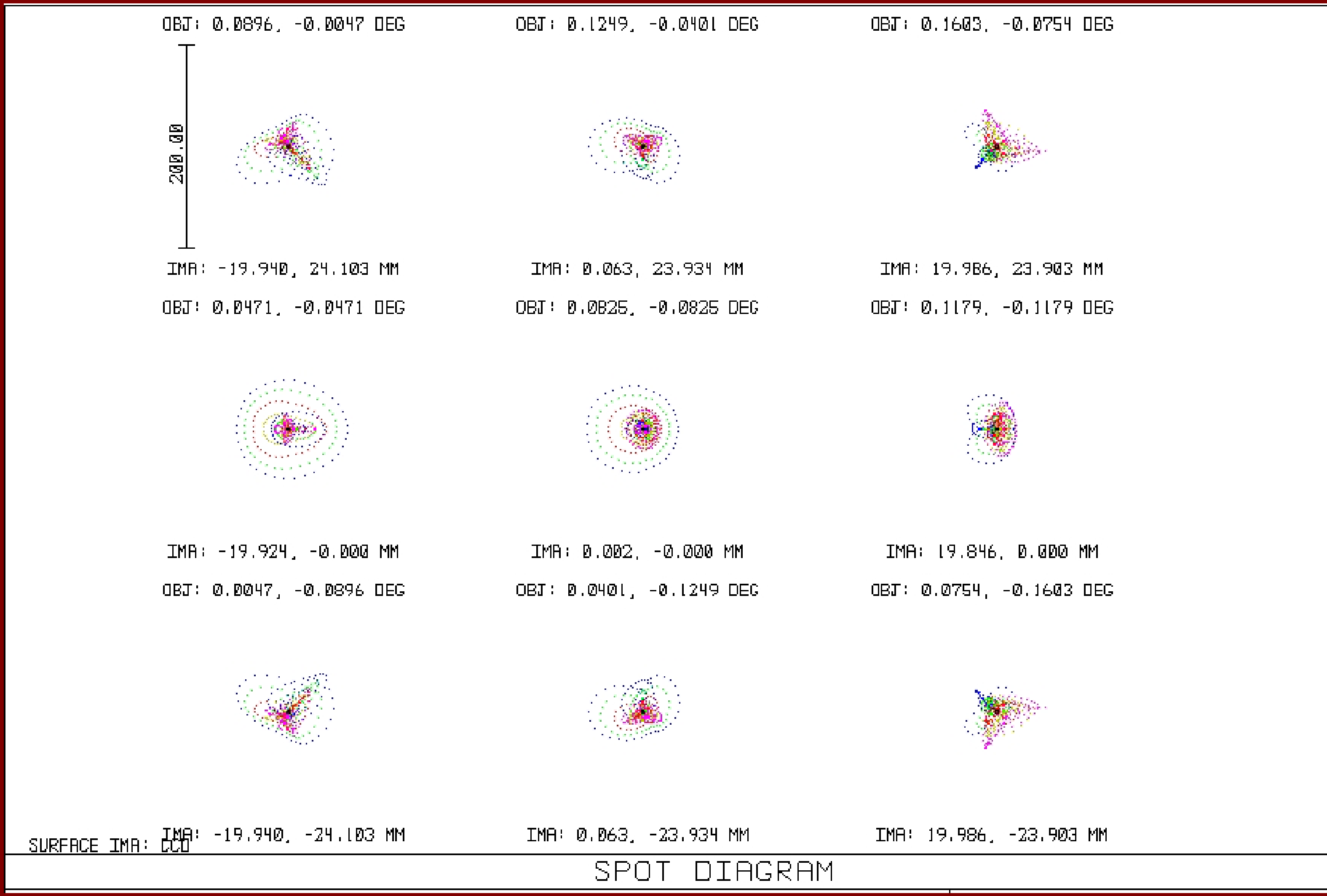
Examples: Slitmask, Z=60



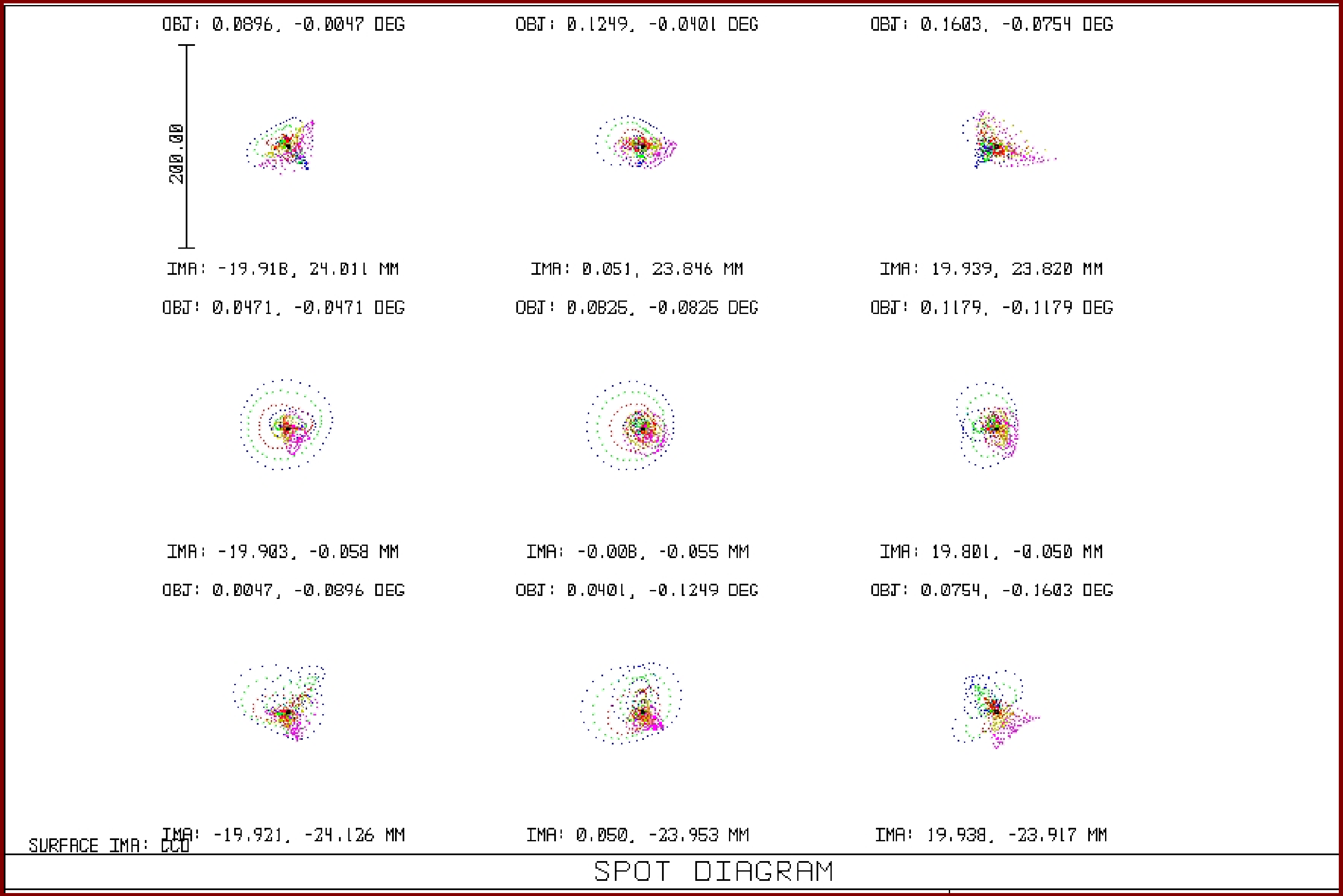
Slitmask, Z=60, with ADC



Examples: LRIS-B, no ADC



Examples: LRIS-B, Z=60, ADC



Optical Design: Issues

These issues arise from the Linear ADC design:

- Plate scale change with ADC in beam (from telescope refocus): ±0.33-arcsec
- CARA must enhance pointing model for displaced focal surface
  - Note that rotator no longer corresponds to optical axis once prisms are separated!
- CARA must add focus change based on prism separation and LRIS rotator angle

Aspheric Modification

- Since the Keck RC design suffers from astigmatism, we explored putting powered surfaces on the prisms to reduce it
- Each section must have axi-symmetric cylindrical power --> aspheres
- Power can only operate over thickness of prism, so back surface must cancel front
- Since prisms are variable thickness, both prisms must have matching surfaces so that power operates over a uniform total thickness

Aspheric Modification: Results

- Ideal system, displaced curved focal surface
- Not directly comparable in fully-open mode, but performance at null position is indicative of actual gain
- Improvement small when convolved w/ seeing

Model	Closed/Nulled rms-Radii (μm)				Open (1700mm) rms-Radii (μm)			
radius→	0	4′	10′	avg	0	4′	10′	avg
No ADC	13	24	145	73 ± 57				
Planar								
2^{nd} order apshere	50	39	97	61 ± 27	51	68	195	104 ± 67
3^{rd} order asphere	56	26	111	63 ± 37	79	82	146	89 ± 43
4^{th} order asphere	43	33	104	[illegible]	[illegible]	[illegible]	164	91 ± 55
4^{th} + 6^{th} order	26	36	99	60 ± 31	70	89	145	87 ± 44

0.503″ 0.601″

0.506″ 0.549″

Aspheric Modification: Cost

- Extra glass:
  - Slight increase in thickness (negligible)
  - Increase in diameter to allow fabrication
- Labor in Lick Optical Shop
  - Estimate 47 weeks
- Total Cost of prism material and fabrication is $452K (vs $272K for planar surfaces)
- Cost increase is $179K

(end of presentation)