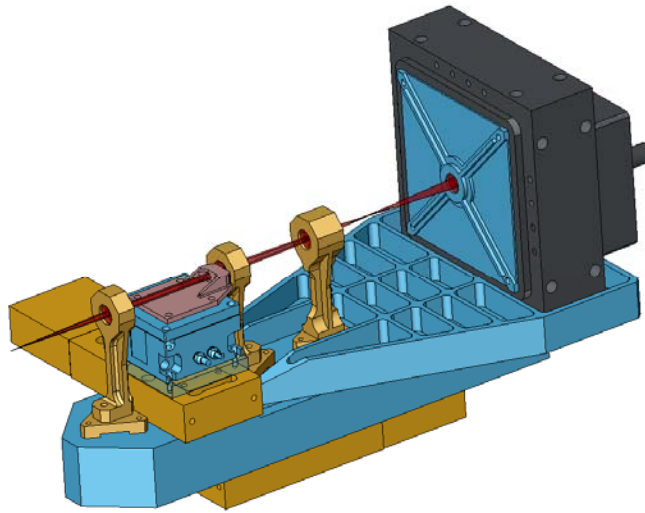


NGAO NGS WFS design review



Caltech Optical Observatories

1st April 2010

Presentation outline

- Requirements (including modes of operation and motion control)
- Introduction
- NGSWFS input feed (performance of the triplet and effect of atmospheric dispersion)
- Modes of operation and pupil mapping
- NGS WFS design (sensor design in all three modes, post-lenslet relay design and performance)
- Summary
- Outstanding issues
- Brief outline of CCID74 performance specs.

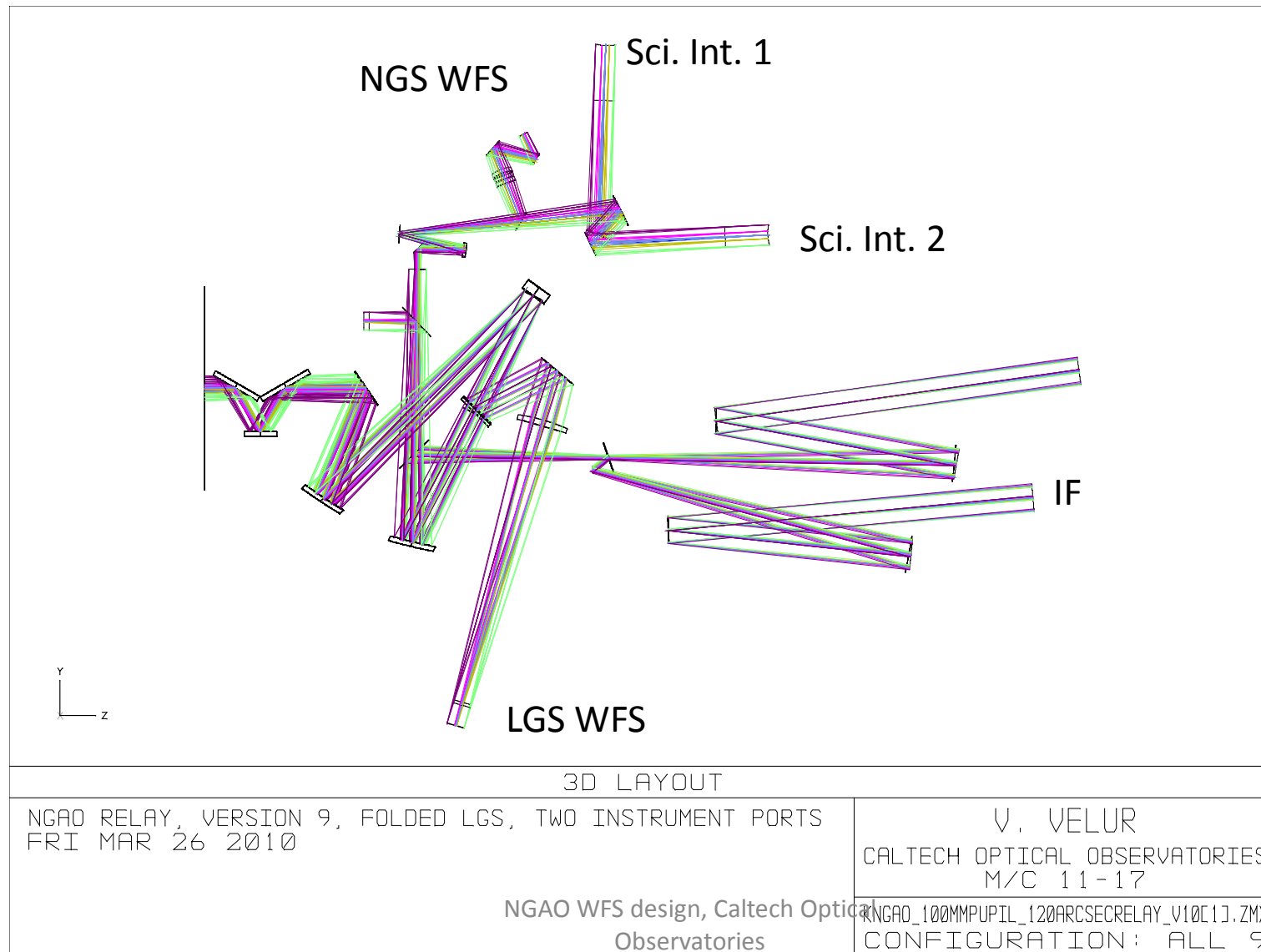
NGS WFS Requirements

- Modes of operation (FR-130 and FR-3247)
 - 63 x 63 sub-apertures
 - 5 x 5 sub-apertures
 - Pupil imaging mode
- Transmission & Operating wavelengths (FR-203 and FR-3444)
 - 500 to 900 nm with transmission of (500nm: 78%, 550nm: 80%, 633nm: 77%, 700nm: 74%, 880nm: 78%).
- Patrol Field of Regard (FR-127)
 - 40 x 60 arcsec rectangle (limited by narrow field relay)
 - NGS WFS Field Steering Mirror Ass'y based pick-off design
- WFS FoV
 - 4 arcseconds in 60 x 60 mode (FR-131)
- Dynamic range (FR-141) = $\pm 1.77''$ @ 700 nm.
- Static non-calibratable aberrations in the NGSWFS = 25 nm (FR-138)
- NGS WFS operates with no ADC (B2C decision)

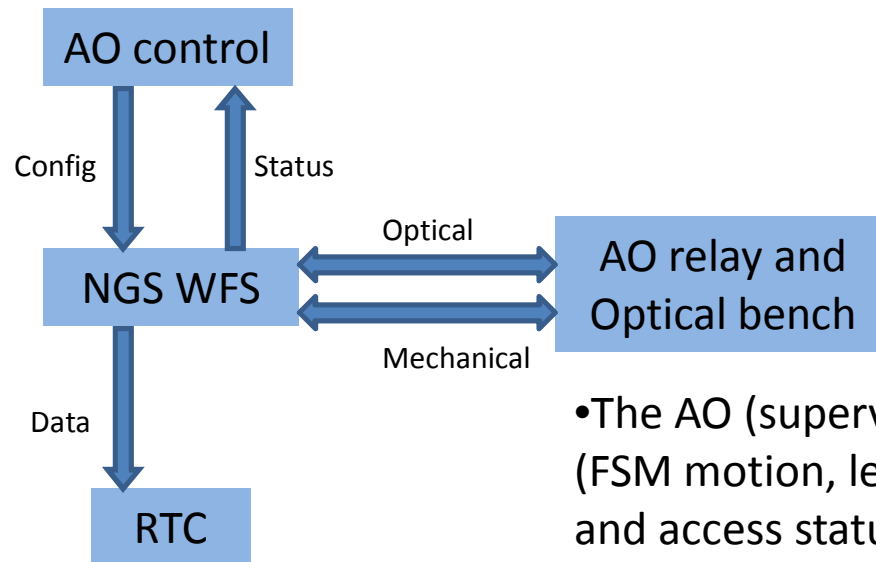
Motion control requirements

- Field steering mirrors – need to be able to pick any star in a 60x40 arcsecond Field of Regard
- Whole WFS motion – the WFS must work with and without the IF dichoric
- Lenslet XY motion & post-lenslet relay and camera focus – the WFS needs to operate in 63x63, 5x5 and pupil imaging modes.

NGAO optical relay – the packaging problem



Context diagram of the NGS WFS

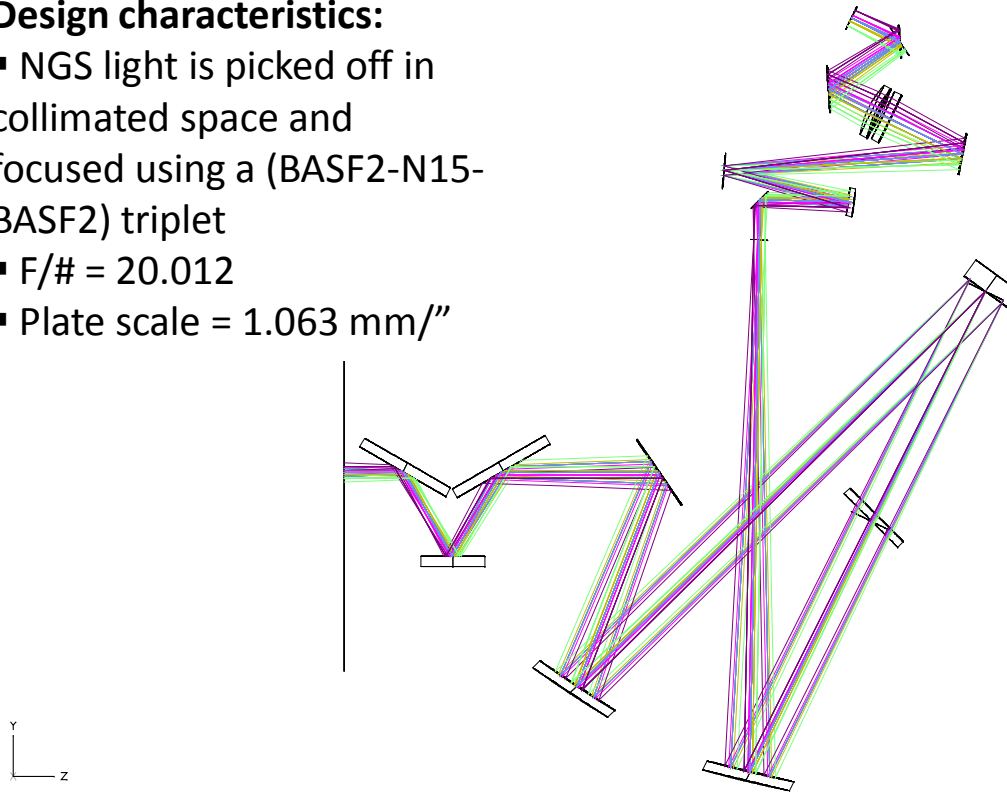


- The AO (supervisory) control can configure (FSM motion, lenslets, read-out mode etc.) and access status signals from the NGSWFS sub-system.
- NGS WFS needs to interface mechanically and optically to the AO relay/ optical bench.
- NGSWFS needs to send pixel data to the RTC.
- Note that the RTC has no control path to the sensor (unlike the LGSWFS where there is a TT mirror control).

Input to the NGS sensor

Design characteristics:

- NGS light is picked off in collimated space and focused using a (BASF2-N15-BASF2) triplet
- $F/\# = 20.012$
- Plate scale = $1.063 \text{ mm}/''$



3D LAYOUT

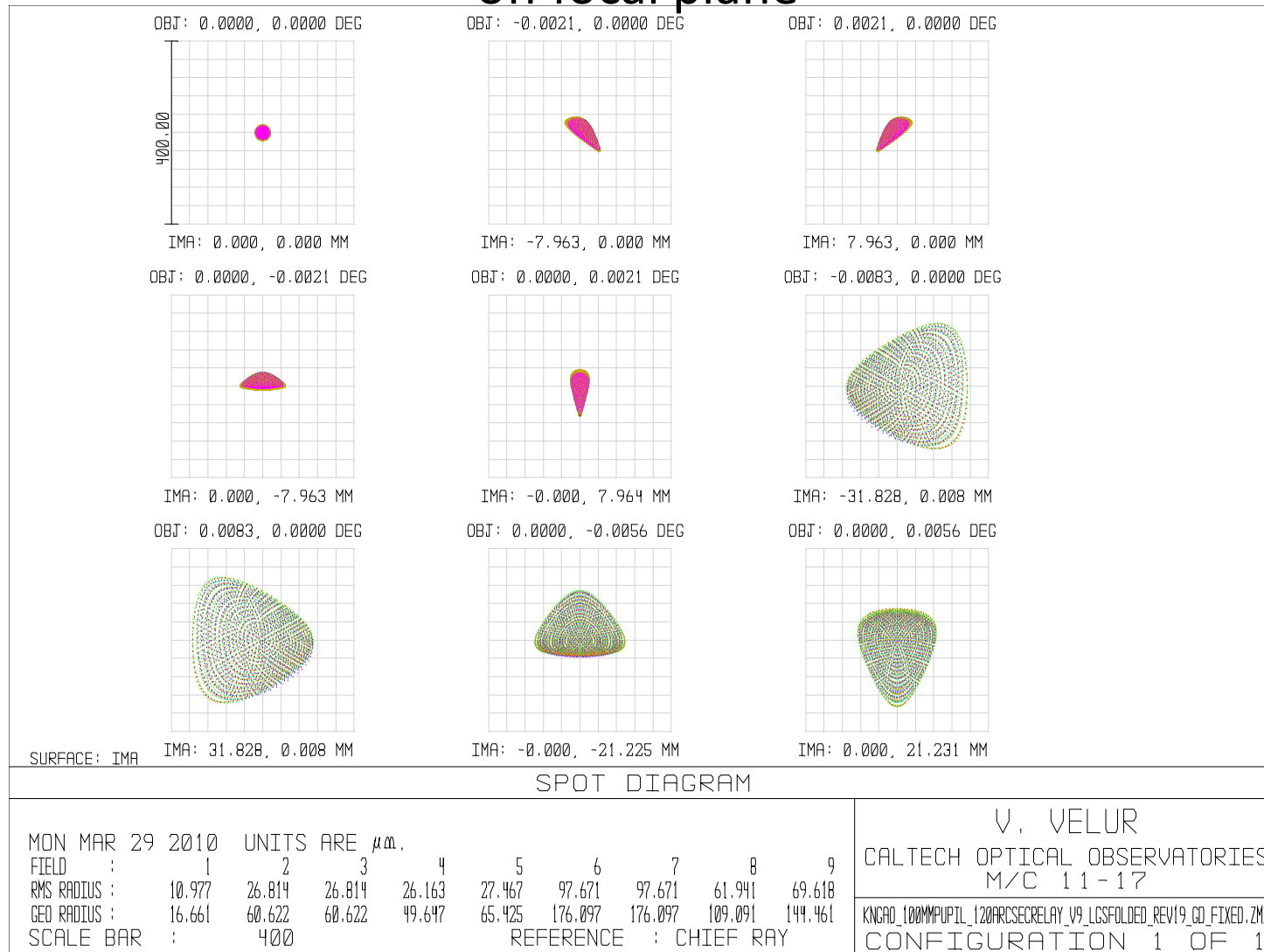
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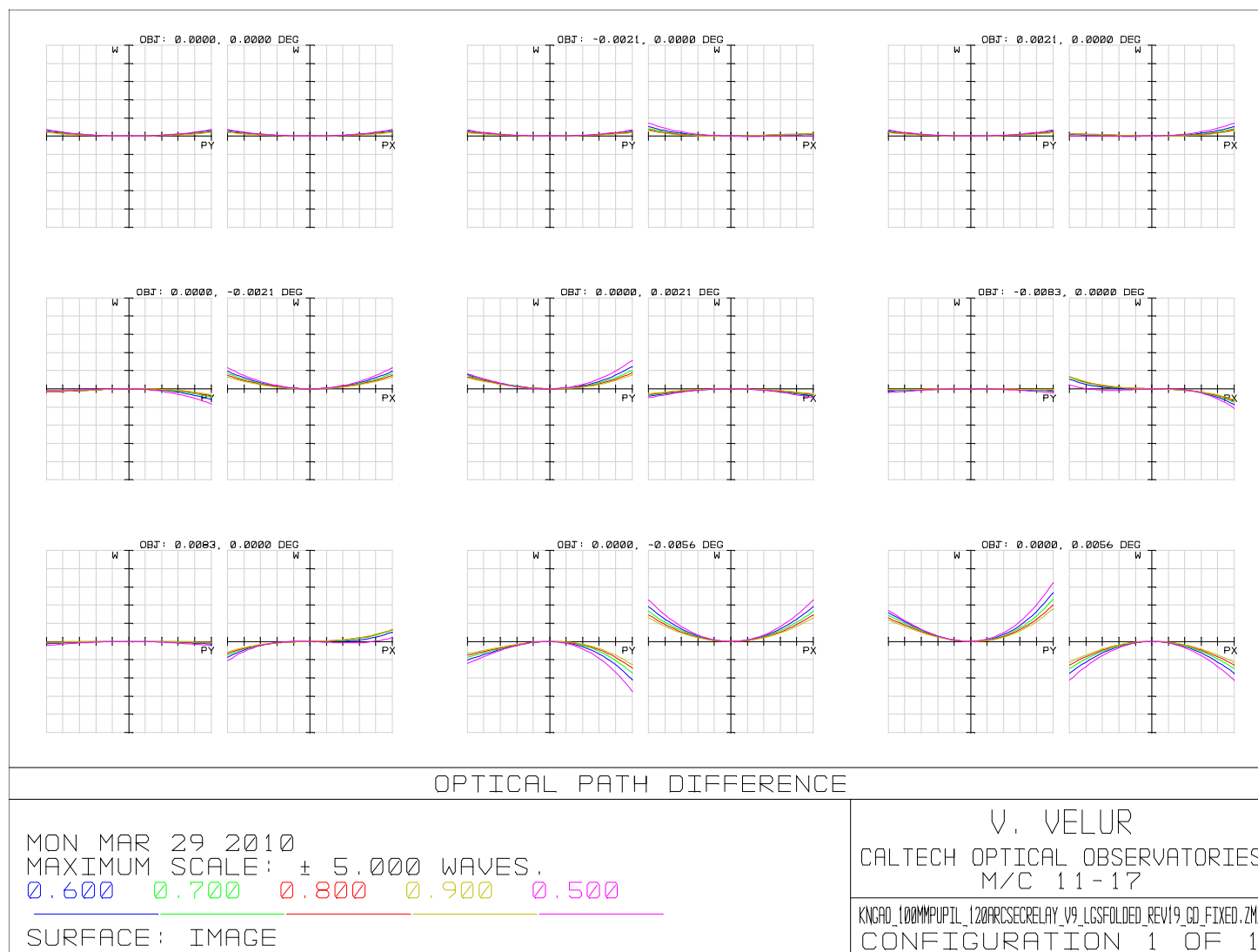
NGAO_100MMPUPIL_120ARCSECRELAY_V9_LGCFOLDED_REV18.ZMX
CONFIGURATION: ALL 1

NGAO WFS design, Caltech Optical
Observatories

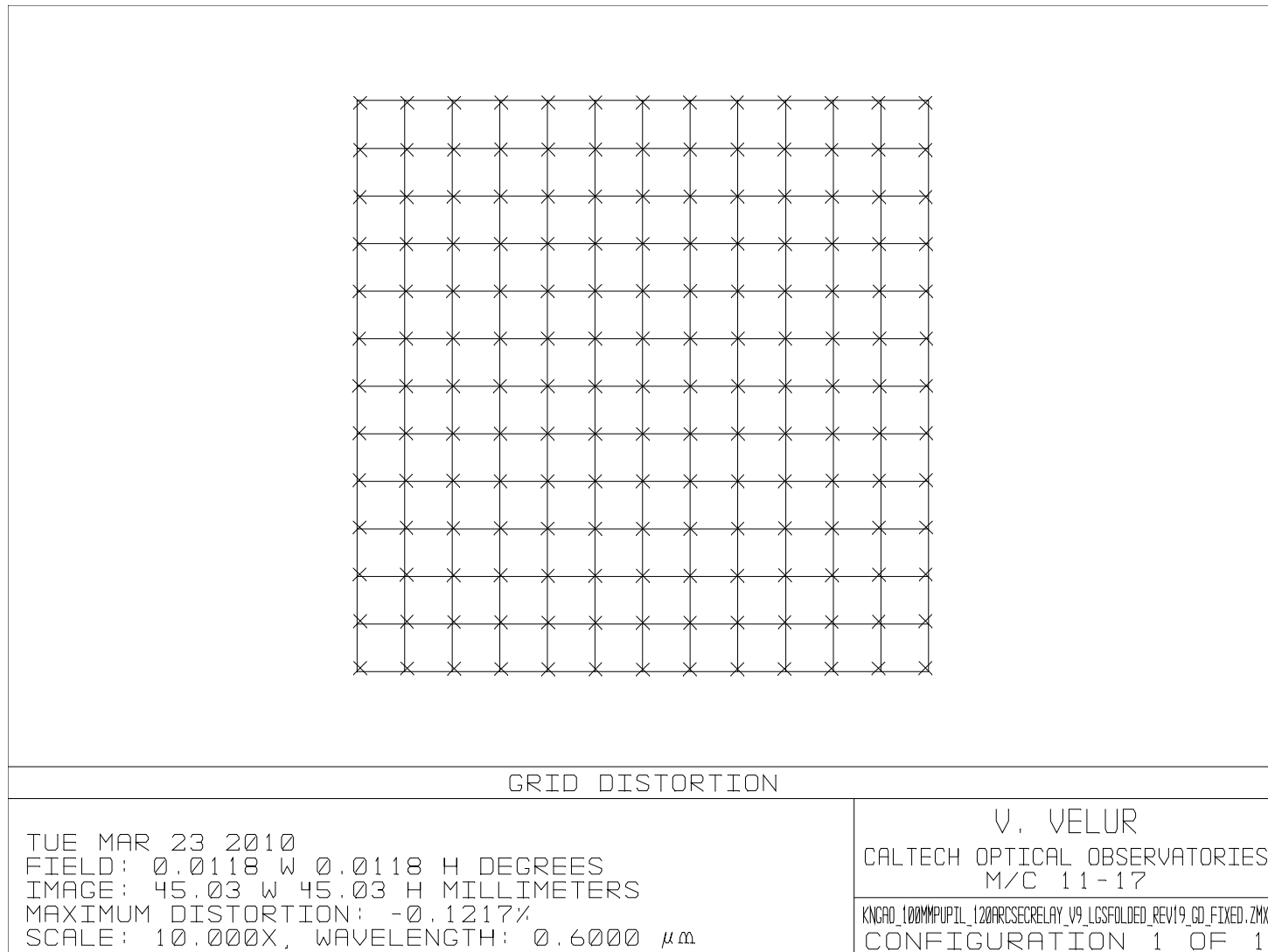
Input to the NGS sensor – spot diagram at the NGS sensor pick-off focal plane



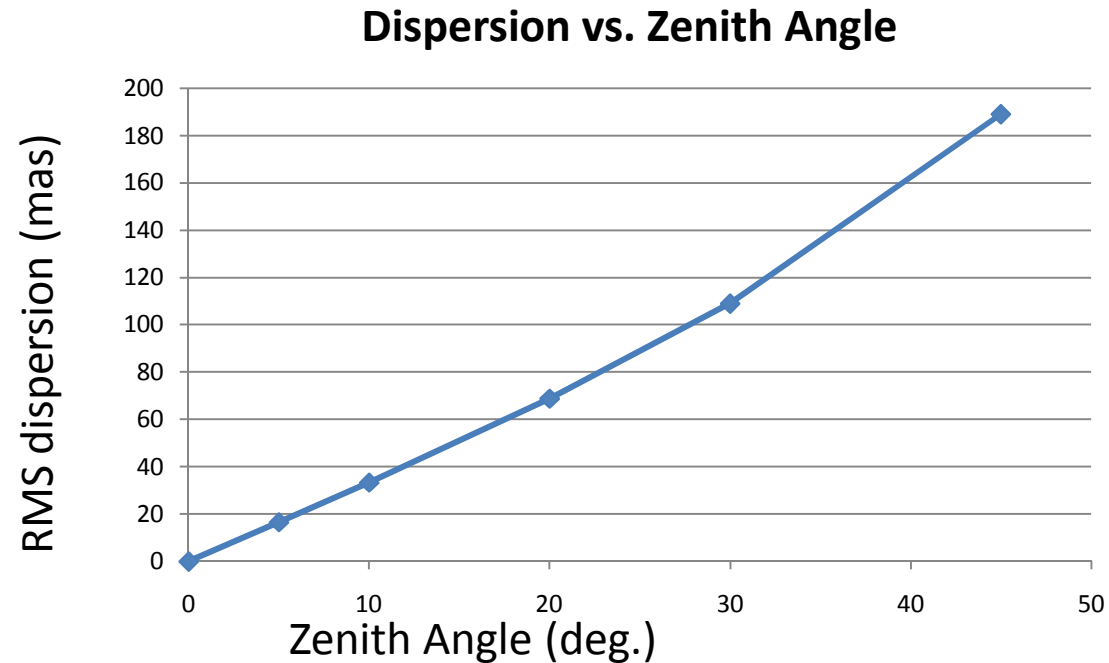
Ray fans at the NGS sensor pick-off focal plane



Grid distortion at the NGS WFS input



Effect of atmospheric dispersion on high order NGS wavefront sensing



Max. dispersion introduced by the atmosphere between 500-900 nm = 189 mas at 45 degree zenith angle – **results spot blurring of 0.2"** [as opposed to 10 mas (RMS) 'nominal' spot blurring with an ADC]

Static aberrations

- Geometric spot size at the relay (RMS) = Error budget alloc. (asec, FWHM)/2.355 (FWHM/RMS) * 21 (um/pixel)/(1asec/pixel)
 - ⇒ We know from the relay design that the spot size is 3 um (RMS), **hence error budget allocation must be 0.33 asec instead of 0.25 asec**. This leads to a 6% change in apparent spot size at the detector.
 - ⇒ Since we will use the NGS WFS with bright stars (Mv>=8), atmospheric fitting error and not measurement error is the dominating error term in the error budget (Fitting error/Measurement error ~2)
- ⇒ We do have a alternate relay design with a extra (field flattening) optic that delivers performance within specs. - it is not clear if this is useful given the sensitivity analysis.

Seeing			
Natural seeing FWHM at GS wavelength	0.43	arcsec	
Subaperture Tip/Tilt corrected FWHM	0.20	arcsec	
AO-compensated FWHM	0.06	arcsec	
Contribution due to seeing	0.20	arcsec	
System Aberrations			
Aberrations in AO thru to WFS	0.25	arcsec	
Atmospheric Dispersion			
ADC in HOWFS? (NO)			
RMS blurring due to atmospheric dispersion	0.109	arcsec	
Total size of detected return beam:	0.34	arcsec	
Charge Diffusion			
Charge Diffusion	0.25	pixels	
Contribution due to Charge Diffusion	0.40	arcsec	
Subaperture Diffraction			
Lambda/d (for sensing)	0.83	arcsec	
Spot size used for centroiding	0.99	arcsec	

Seeing			
Natural seeing FWHM at GS wavelength	0.43	arcsec	
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AO-compensated FWHM	0.06	arcsec	
Contribution due to seeing	0.20	arcsec	
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Charge Diffusion			
Charge Diffusion	0.25	pixels	
Contribution due to Charge Diffusion	0.40	arcsec	
Subaperture Diffraction			
Lambda/d (for sensing)	0.83	arcsec	
Spot size used for centroiding	1.05	arcsec	

What's the implication for the NGS WFS?

- Wavefront error on input beam is 1.15 waves RMS (6 waves P-V) @ 600 nm at the extreme (and worst case) field points. This is mostly astigmatism.
- As per KAON 685 we know that this corresponds to ($y = ar^2 \rightarrow 0.69 * 10^{-6} = 25 * a \rightarrow a = .276 * 10^{-7}$);
 $dy/dr = 2*a*r \rightarrow dy/dr = 0.2 * 10^{-6}$) [*c.f. Figure 13 in the KAON*]
- KAON 692 Figures 9 and 10 along with corresponding analysis also indicate that for a large # of sub-apertures (60 in our case) the sub-ap spot size due to input aberration is going to be of the order of 2 μ m (RMS).

Analysis result

- Impact of input aberrations
 - Negligible impact on sub-aperture spot size.
 - Acceptable centroid offsets (~ 0.1 pixel worst case)
 - Small amount of distortion (0.13%) will be calibrated using stimulus and acquisition camera.
 - Chromatic aberrations acceptable
- The dynamic range of the sensor is ± 2 asec (within spec.)
- Atmospheric dispersion introduces **0.19 asec** of spot blurring.
- **The WFS relay is slightly out of spec., but sensitivity analysis reveal that this is not the bottleneck for performance with bright guide stars (request for change of specs).**

NGS WFS parameters

- Following Keck Drawing [Drawing #1410-CM0010 Rev. 1](#), we have 59 (+1/2+1/2) WFS sub-apertures across the a circle that inscribes the Keck primary mirror. We also support another calibration mode with 5x5 pupil samples across the Keck primary mirror.
- The WFS FoV is 4" because the sensor needs to track extended objects that are 4" in diameter. One could also work out the spot size. This give us a p-value (ratio of pixel size to spot size) = 1

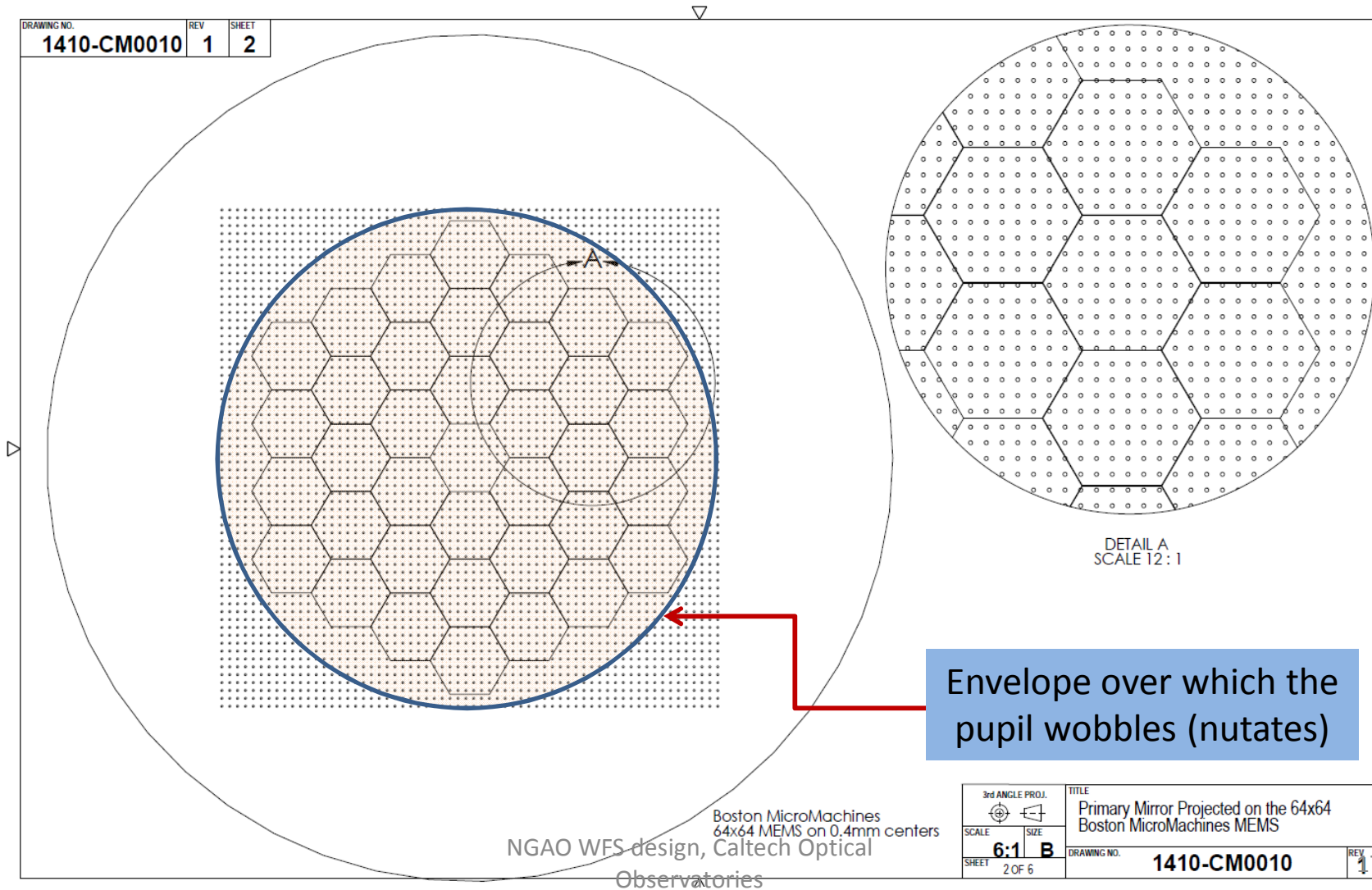
For sanity check, we also calculate the apparent spot size at the detector.

Seeing			
Natural seeing FWHM at GS wavelength	0.43	arcsec	
Subaperture Tip/Tilt corrected FWHM	0.20	arcsec	
AO-compensated FWHM	0.06	arcsec	
Contribution due to seeing	0.20	arcsec	
System Aberrations			
Aberrations in AO thru to WFS	0.40	arcsec	
Atmospheric Dispersion			
ADC in HOWFS? (NO)			
RMS blurring due to atmospheric dispersion	0.109	arcsec	
Total size of detected return beam:	0.34	arcsec	
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Charge Diffusion	0.25	pixels	
Contribution due to Charge Diffusion	0.40	arcsec	
Subaperture Diffraction			
Lambda/d (for sensing)	0.83	arcsec	
Spot size used for centroiding	1.05	arcsec	

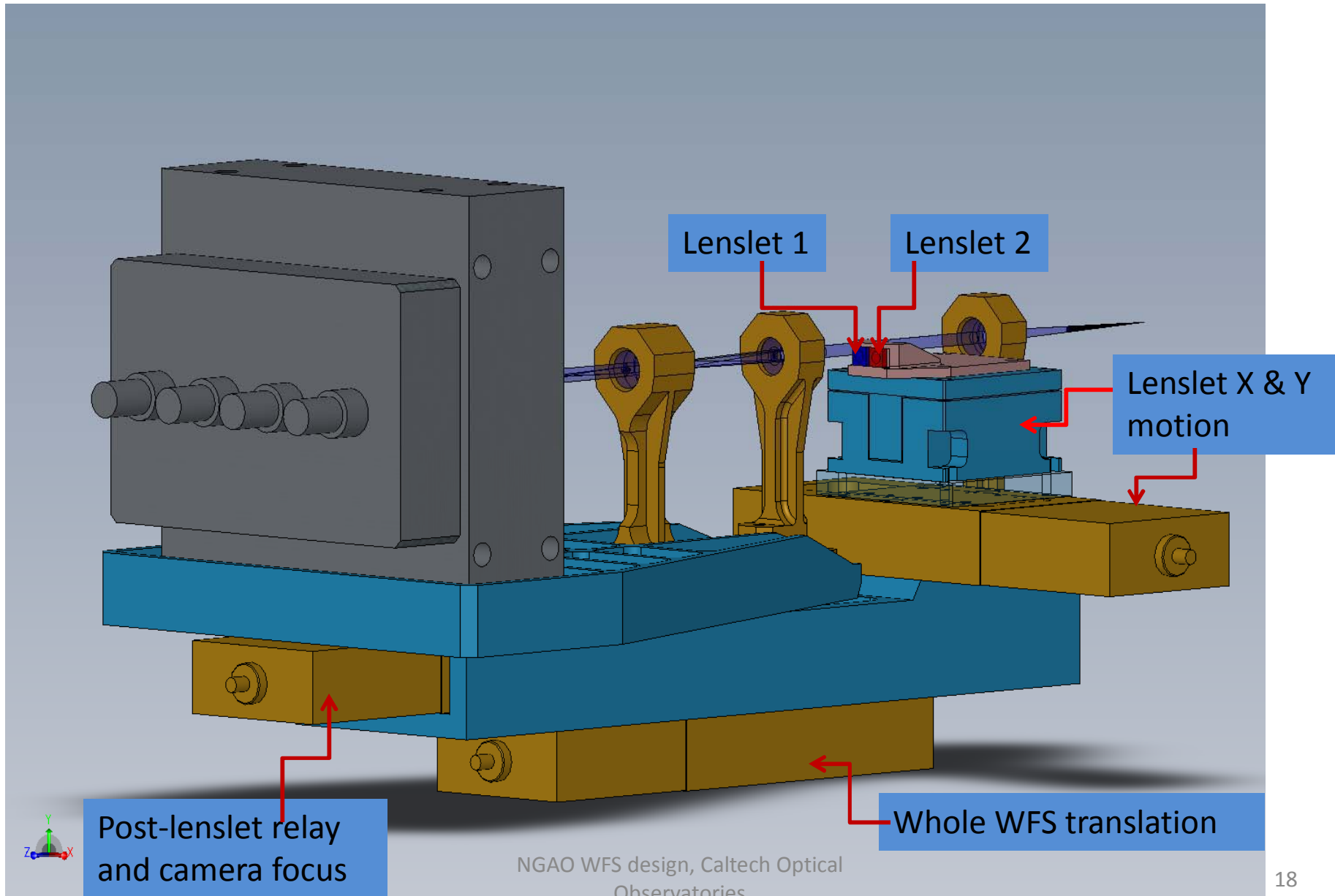
Modes of operation

- 63x63 sub-ap. mode of operation
 - We use 4 physical pixels per sub-ap. Which can be binned on chip and read as 2x2 pixels/sub-aperture with almost zero read noise penalty. This gives us the flexibility of 2 modes, one with high linearity and another with lower read noise.
 - Only 59x59 sub-apertures are lit by NGS star light at any time. The pupil imaged by the WFS nutates around the 63x63 sub-apertures.
- 5x5 mode of operation
 - to simplify the size of moving parts while facilitating the two pupil sampling modes, we use the same collimator and post-lenslet relay for both the 63 and 5 sub-ap mode of operation.
 - We choose 48 pixels/sub-aperture (instead of 50 pixels/sub-ap) to enable 4x4 binned pixel/sub-aperture operation with standard centroiding algorithms.
 - A small fraction of light will be lost from the outer-most sub-apertures due to pupil nutation.
- Pupil imaging mode – The NGS WFS can image the pupil using the WFS camera.

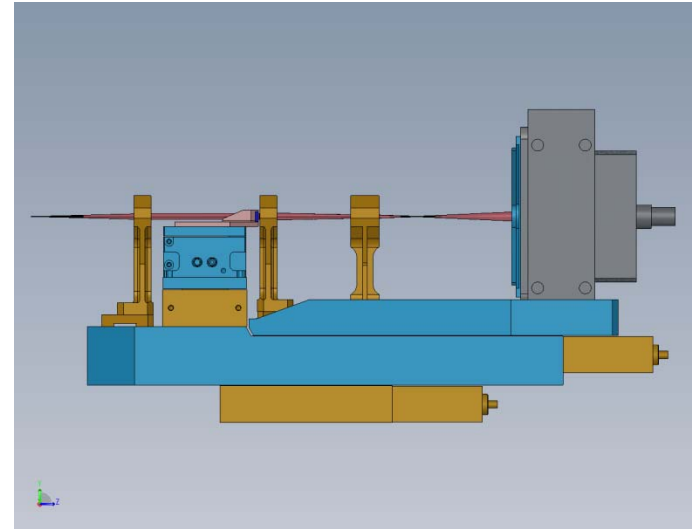
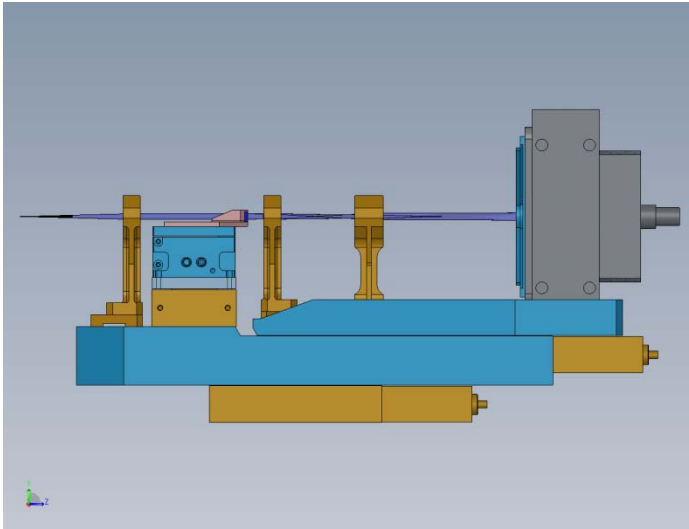
Keck primary projected on the 64x64 actuator BMM HODM



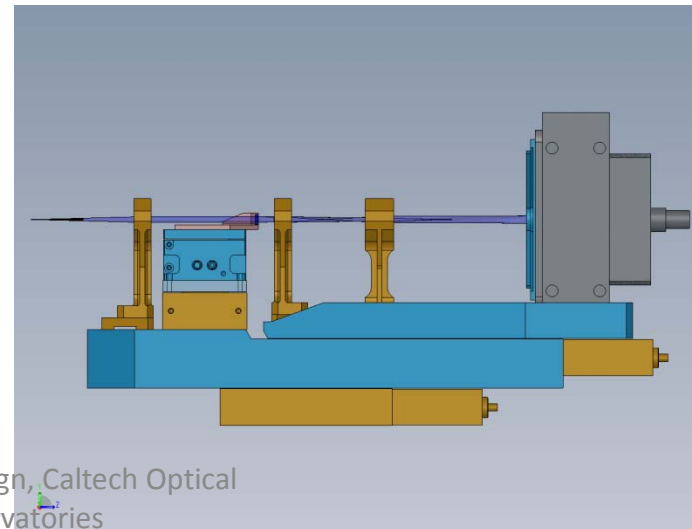
Motion control



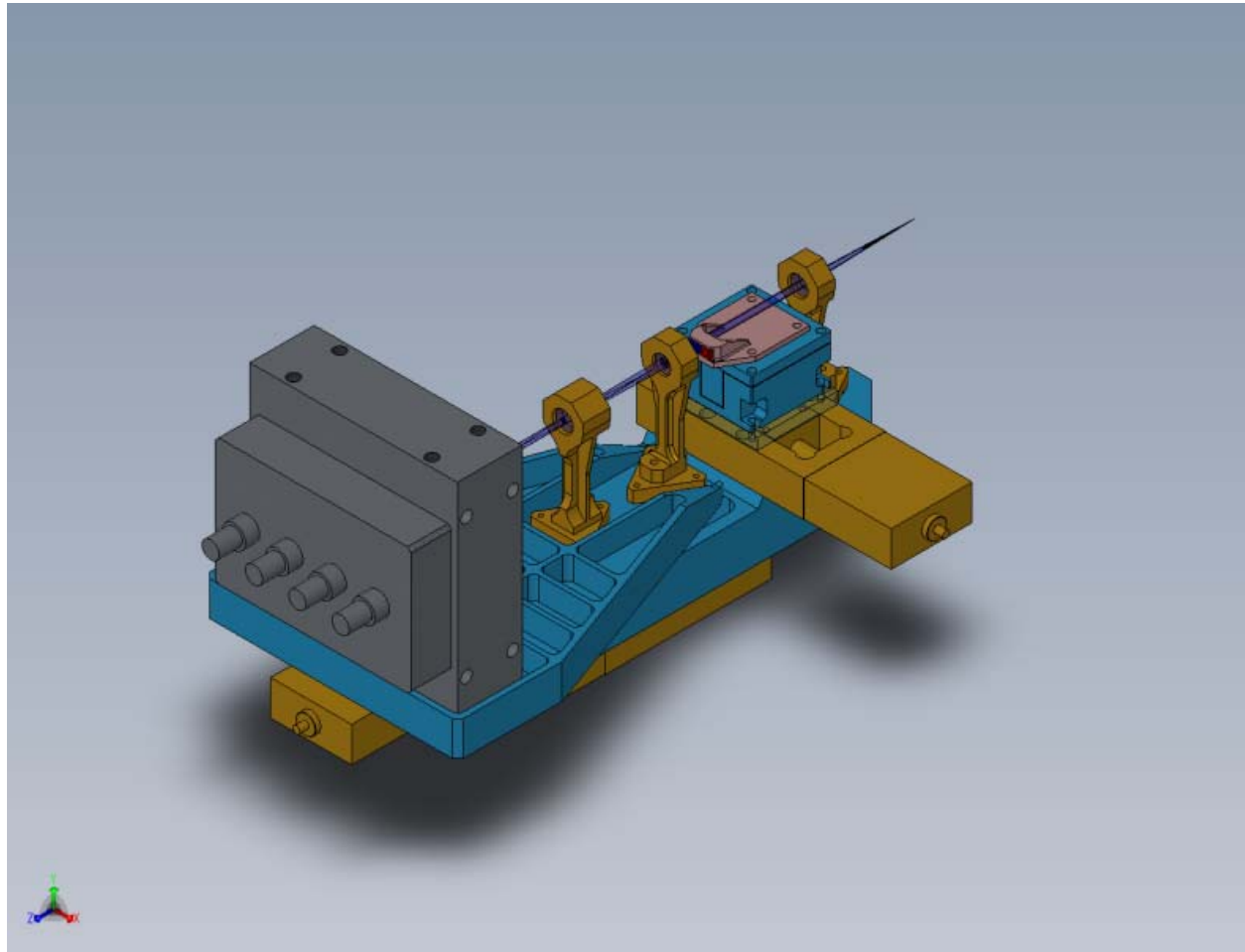
Modes of operation cont'd



Modes(Clockwise from top): 5x5, 63x63 and pupil imaging modes



Modes of operation cont'd



Pupil mapping between NGSWFS-DM and primary mirror

As per [Drawing #1410-CM0010 Rev. 1](#), :

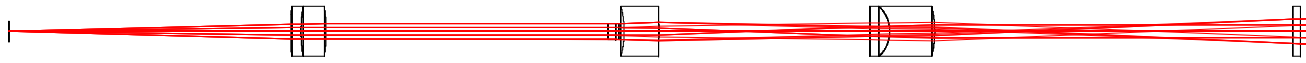
- The whole DM would be mapped by using a pupil that is $25.2 \text{ mm}/24 \text{ mm} * 10.949 = 11.49645 \text{ m}$ and has the same focal length (149.583 m). This corresponds to an $F/\# = 13.01123$.
- Plate scale = $13.01123 * 11.49645 / (180/\pi * 3600) = 725.1979 \text{ um/''}$ at the telescope focal plane
- The apparent plate scale at the NGS pick off focal plane is 19.06163 (instead of 20.012). The plate scale is 1.0623 mm/''.

WFS design parameters

Parameter	60x60 mode	5x5 mode	units
f_collimator	60	60	mm
Input plate scale	1.0623	1.0623	mm/"
Binned pixel size (# of pixels)	1	12	pixels
Detector plate scale (mm/")	0.0210	0.2520	mm/"
Plate scale ratio (IPS/DPS)	50.58	4.22	
input f/#	19.06	19.06	
pupil sampling	63	5	sub-aps across pupil
d_lenslet	0.05	0.60	mm
de-magnification (m)	1.68	1.68	
f_lenslet	0.71	8.47	mm
f# lenslet	14.12	14.12	
wavelength (for worst case FN calc.)	0.90	0.90	um
fresnel #	0.98	11.80	
radius of curvature of lenslet	0.36	4.38	mm

63x63 NGS WFS layout

- Total relay length = 262 mm
- Components from (left to right) –collimating doublet, lenslet array, field singlet, focusing doublet followed by the window and the detector.
- Wavelength of operation – 500-900 nm (*TBC*)



3D LAYOUT

MON MAR 29 2010

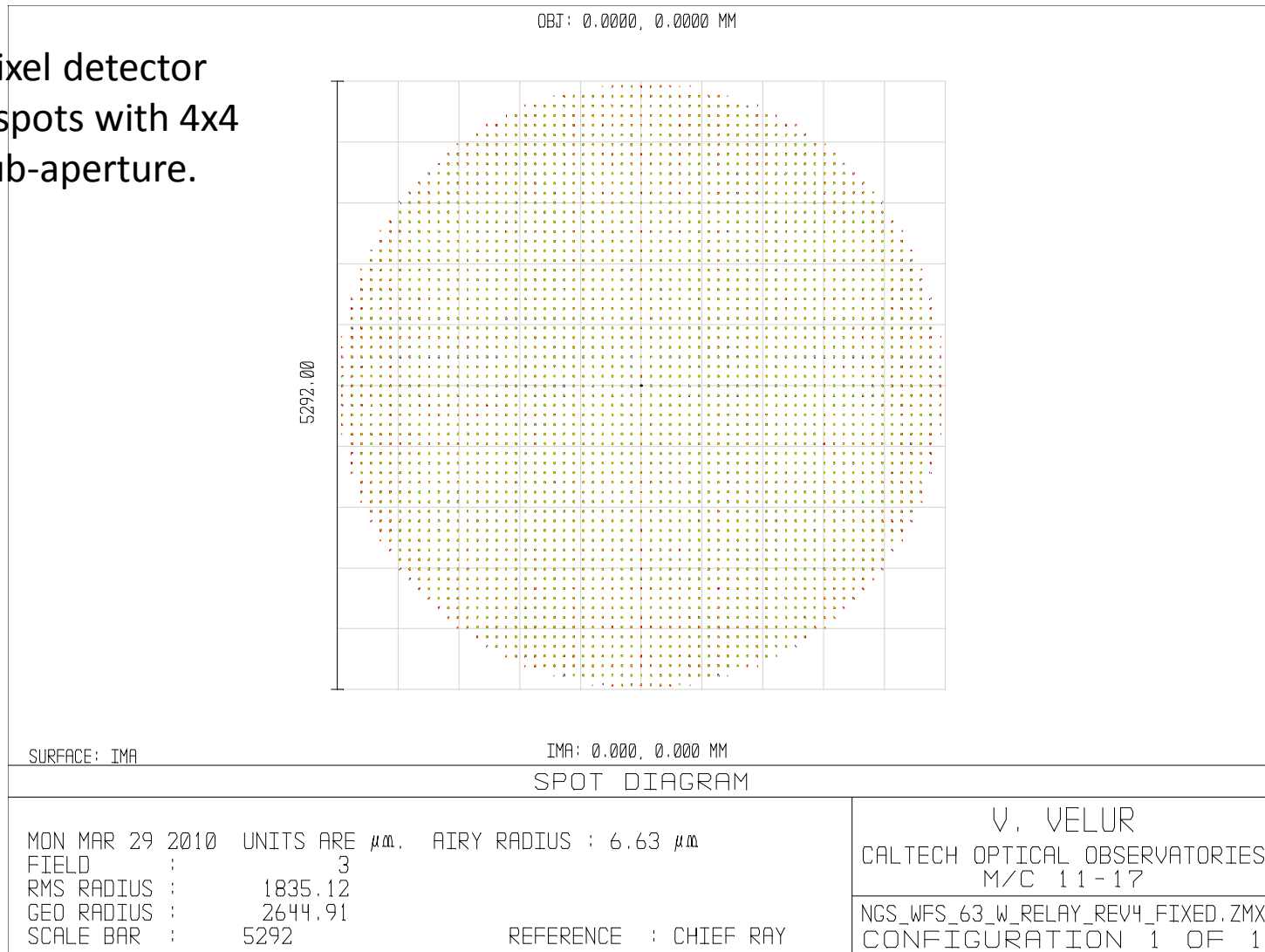
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NGS_WFS_63_W_RELAY_REV4_FIXED.ZMX
CONFIGURATION: ALL 1

NGAO WFS design, Caltech Optical
Observatories

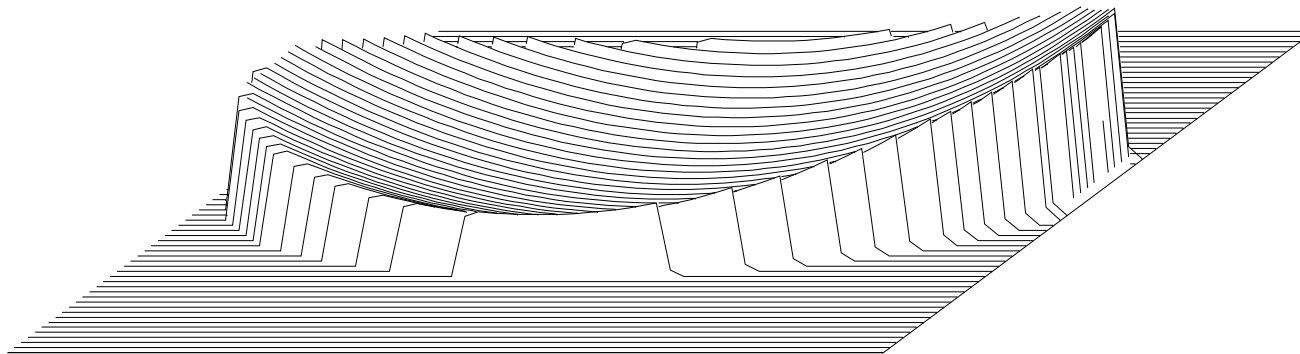
63x63 sub-aperture NGS WFS spots

21 um pixel detector
with 63 spots with 4x4
pixels/sub-aperture.



NGAO WFS design, Caltech Optical
Observatories

63x63 NGS WFS layout



WAVEFRONT FUNCTION

FRI MAR 26 2010
0.5000 μm AT 2.1246, 0.0000 MM
PEAK TO VALLEY = 0.1387 WAVES, RMS = 0.0299 WAVES.
SURFACE: 4 (CUSTOM LENSLET)
EXIT PUPIL DIAMETER: 3.1471E+000 MILLIMETERS

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NGS_WFS_63_W_RELAY_REV5.ZMX
CONFIGURATION 1 OF 1

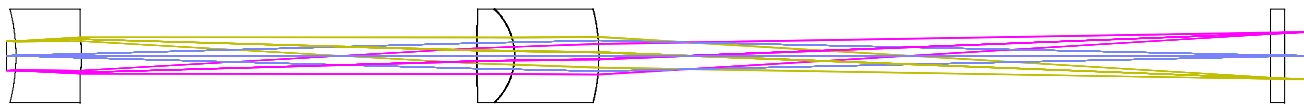
NGAO WFS design, Caltech Optical
Observatories

63x63 NGS WFS layout

Lens Data Editor													
Edit Solves View Help													
Surf	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic	Par 0(unused)	Par 1(unused)	Par 2(unused)	Par 3(unused)	Par 4(unused)	Par 5(unused)
OBJ	Standard		Infinity	56.502		2.125	0.000						
1*	Standard		83.790	2.000	N-SF5	5.000	U	0.000					
2*	Standard		28.120	5.000	N-BK7	5.000	U	0.000					
3*	Standard	45267	-35.920	56.500		5.000	U	0.000					
4	Standard	custom lenslet	Infinity	1.500	N-BK7	1.607		0.000					
ST0	Lens Array		-0.365	0.706		1.581	0.000		63.000	63.000	0.051	0.051	
6	Standard		Infinity	1.000		1.606	0.000						
7*	Standard	custom singlet	-19.621 V	7.000	F2	5.000	U	0.000					
8	Standard		-14.189 V	42.189 V		2.065	0.000						
9*	Standard	custom doublet	257.699 V	4.000	BAFN10	5.000	U	0.000					
10*	Standard		-6.849 V	9.000	SF10	5.000	U	0.000					
11*	Standard		-20.361 V	71.668 V		5.000	U	0.000					
12*	Standard		Infinity	1.500	BK7	5.000	U	0.000					
13	Standard		Infinity	3.000		2.503	0.000						
14	Standard		Infinity	0.000		2.652	0.000						
IMA	Standard		Infinity	-		2.652	0.000						

63x63 NGS WFS post lenslet relay

- Mag. = 1.681
- Total relay length = 139 mm



3D LAYOUT

MON MAR 29 2010

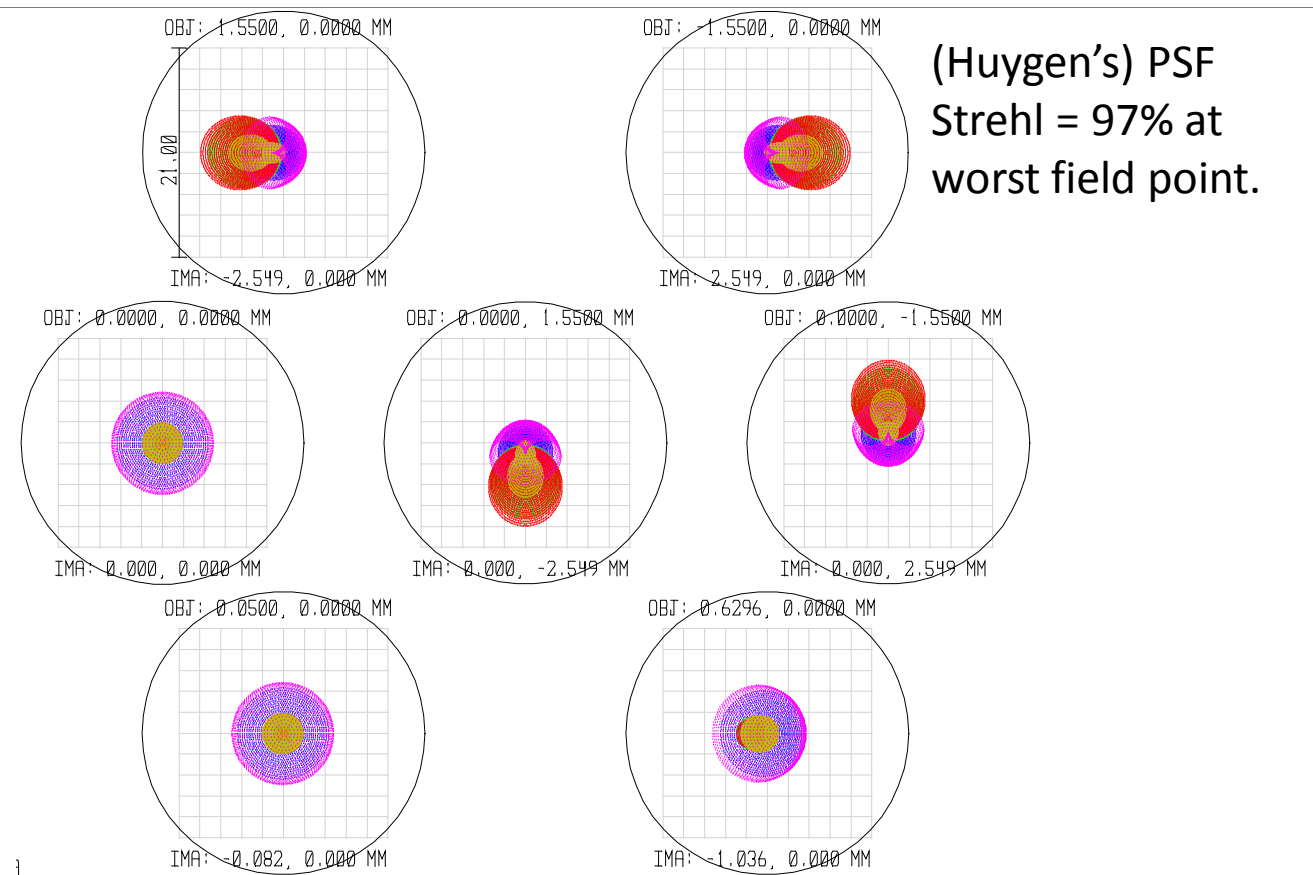
NGAO WFS design, Caltech Optical
Observatories

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NGS_63_RELAY_REV8.ZMX
CONFIGURATION: ALL 1

Post lenslet relay – spots delivered by the relay

3 μm RMS spot size corresponds to 0.33asec (FWHM) static error in the sensor @ 1asec/pixel plate scale

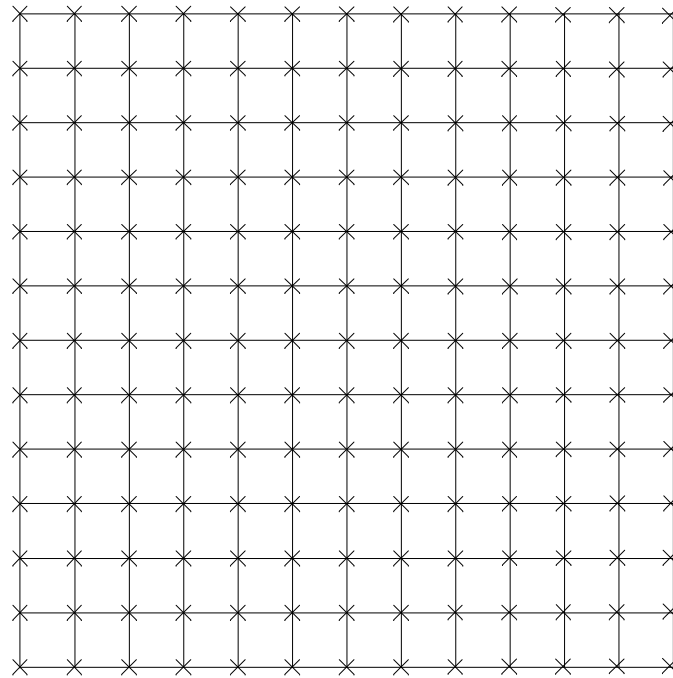


SPOT DIAGRAM

MON MAR 29 2010								UNITS ARE μm .		AIRY RADIUS : 14.22 μm					V. VELUR	
FIELD :	1	2	3	4	5	6	7	CALTECH OPTICAL OBSERVATORIES								
RMS RADIUS :	2.883	2.883	1.742	2.883	2.883	1.742	1.809	M/C 11-17								
GEO RADIUS :	8.314	8.314	5.112	8.314	8.314	5.186	5.494	NGS_63_RELAY_REV8.ZMX								
SCALE BAR :	21		REFERENCE : CHIEF RAY					CONFIGURATION 1 OF 1								
NGAO WFS design, Caltech Optical																

NGAO WFS design, Caltech Optical
Observatories

Post lenslet relay – grid distortion



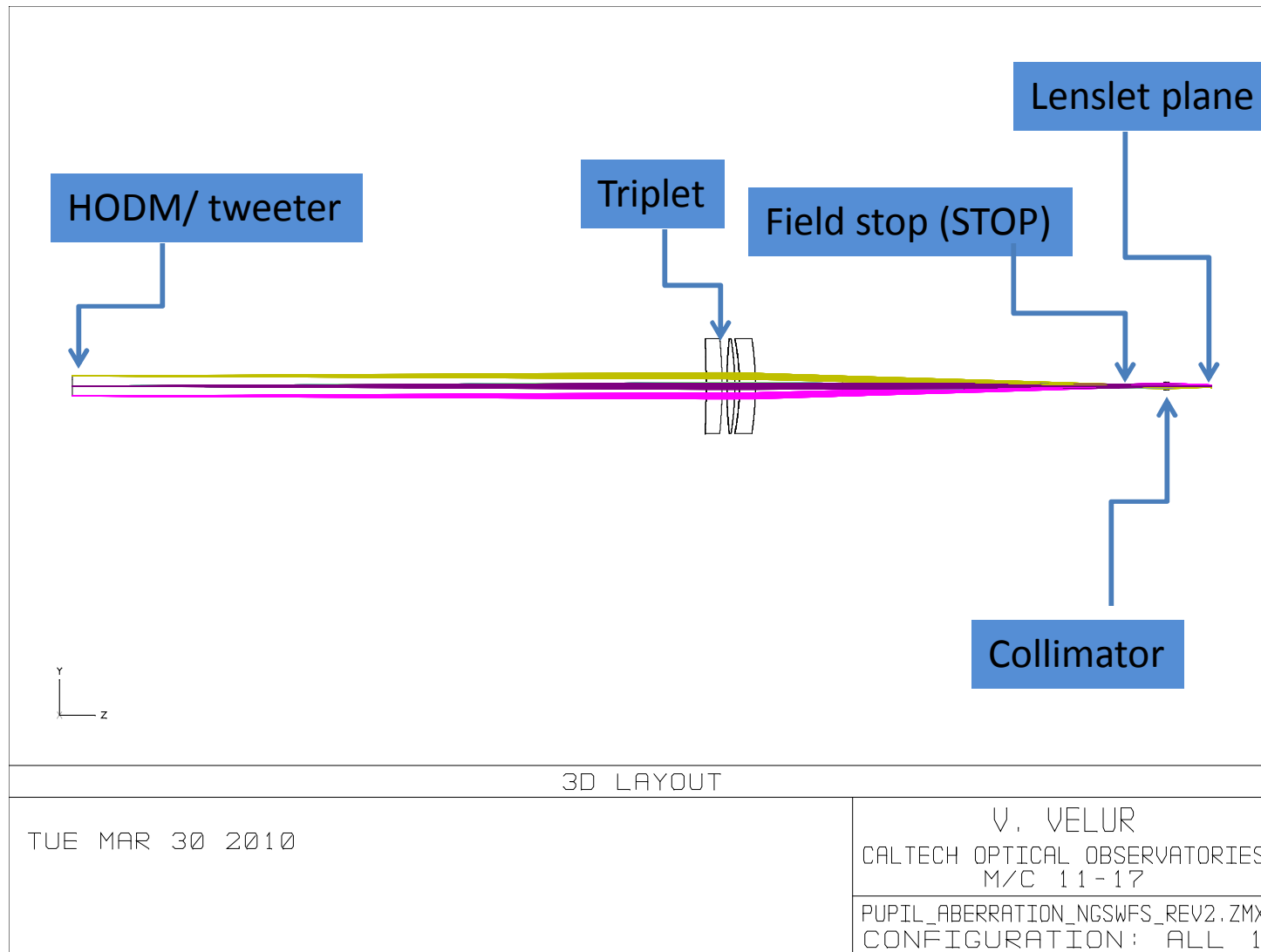
The worst case sub-aperture spot motion due to distortion will be less than 0.1 of a pixel.

GRID DISTORTION

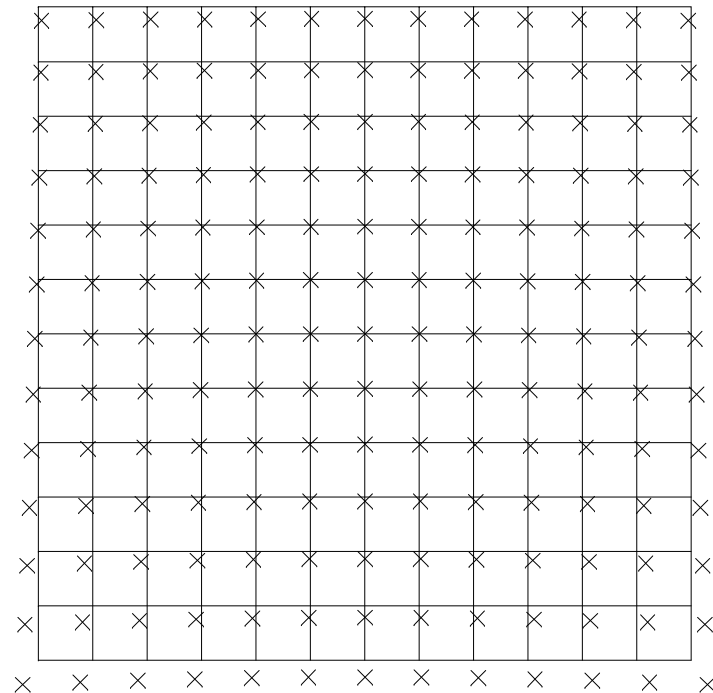
MON MAR 29 2010
FIELD: 2.19 W 2.19 H MILLIMETERS
IMAGE: 3.61 W 3.61 H MILLIMETERS
MAXIMUM DISTORTION: -0.0793%
SCALE: 10.000X, WAVELENGTH: 0.7000 μm

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NGS_63_RELAY_REV8.ZMX
CONFIGURATION 1 OF 1

Pupil (HODM to Lenslet) mapping layout



Grid distortion in pupil mapping



Extreme actuator-lenslet mapping is off by 2%

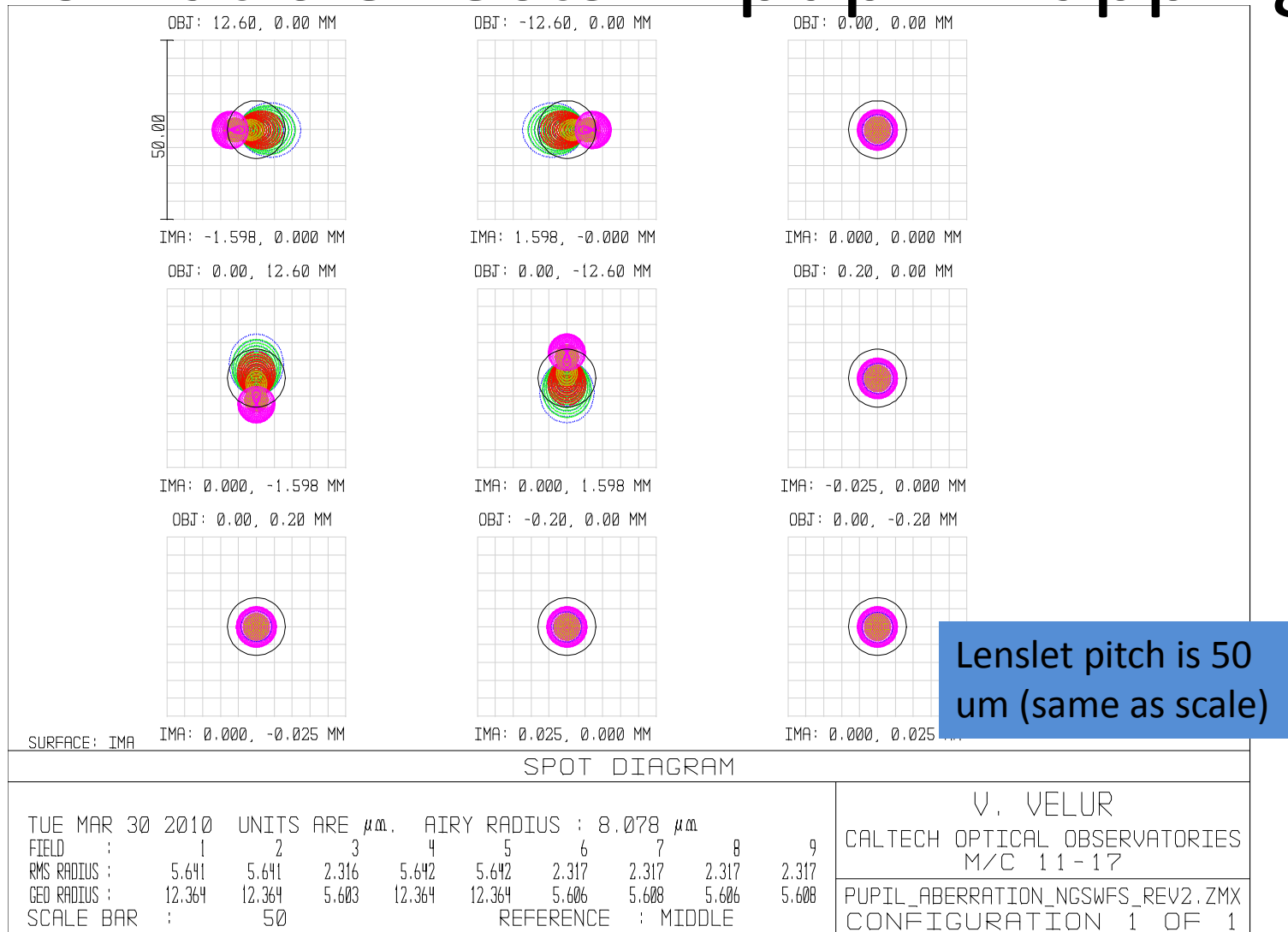
GRID DISTORTION

TUE MAR 30 2010
FIELD: 17.82 W 17.82 H MILLIMETERS
IMAGE: 2.27 W 2.27 H MILLIMETERS
MAXIMUM DISTORTION: 0.0626%
SCALE: 100.000X, WAVELENGTH: 0.7000 μm

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M/C 11-17

PUPIL_ABERRATION_NGSWFS_REV2.ZMX
CONFIGURATION 1 OF 1

Chromatic effects in pupil mapping

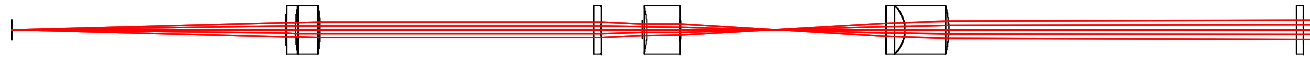


Results of pupil mapping analysis

- Distortion in mapping of actuators to lenslets is $>2\%$ at the extreme sub-apertures.
- Point actuators are mapped onto $>4\text{ }\mu\text{m}$ RMS dia. Blobs *[compare to influence function of an actuator]*.
- Chromatic effects make this blob as big as $12\mu\text{m}$ (RMS) *[compare to influence function of an actuator]*.
- **Need to model chromatic effects all the way from the field points on the primary mirror with entrance window, LGS dichroic, w/ and w/o IF dichroic in the optical relay to the WFS lenslet and compare with the actuator influence function.**

5x5 NGS (calibration) WFS layout

- Total relay length = 269 mm
- Components from (left to right) –collimating doublet, lenslet array, field singlet, focusing doublet followed by the window and the detector.
- Wavelength of operation – 500-900 nm



3D LAYOUT

MON MAR 29 2010

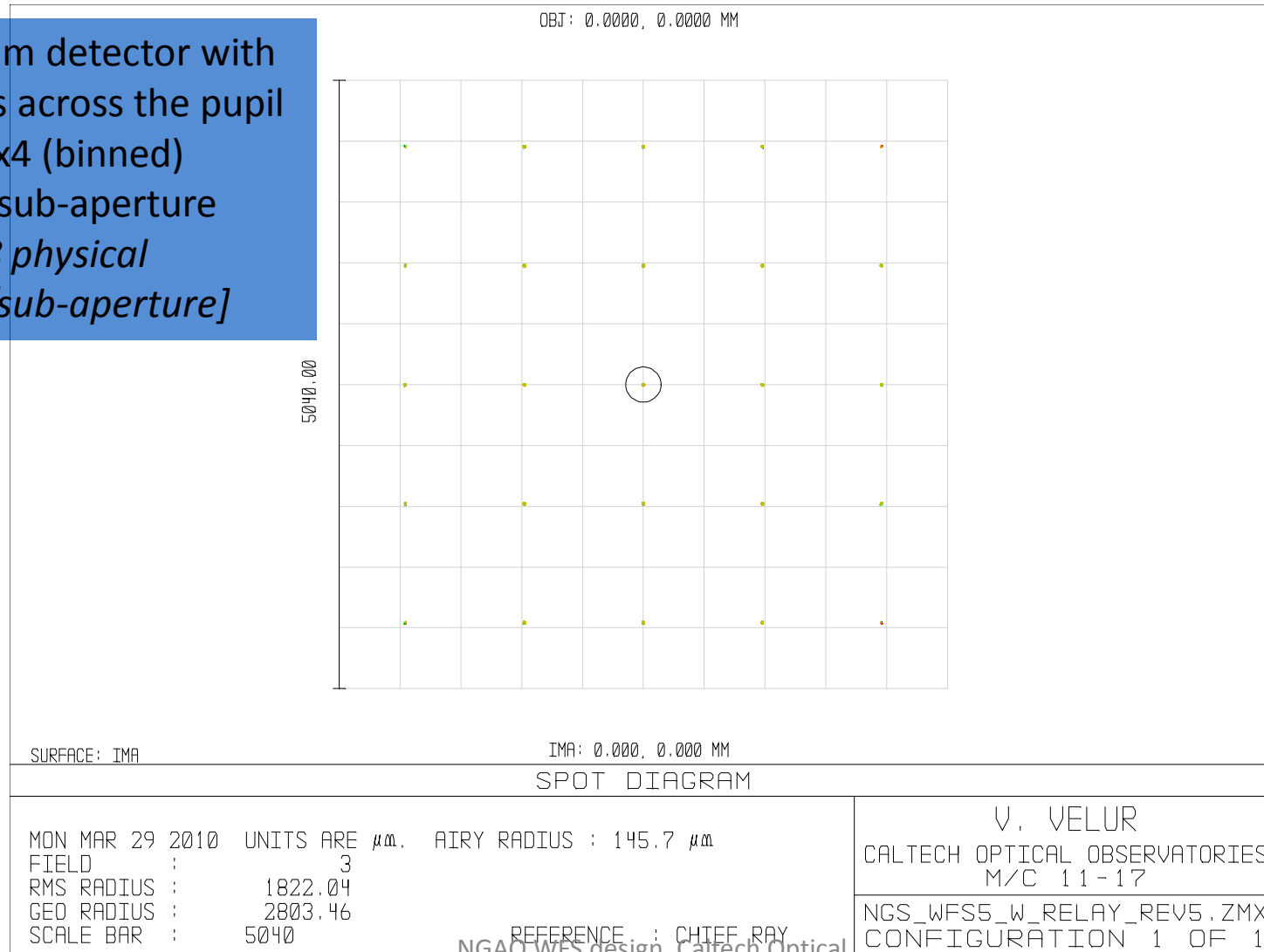
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M/C 11-17

NGS_WFS5_W_RELAY_REV5.ZMX
CONFIGURATION: ALL 1

NGAO WFS design, Caltech Optical
Observatories

5x5 NGS WFS layout RD11 RD10

5040 um detector with
5 spots across the pupil
with 4x4 (binned)
pixels/sub-aperture
[48x48 physical
pixels/sub-aperture]



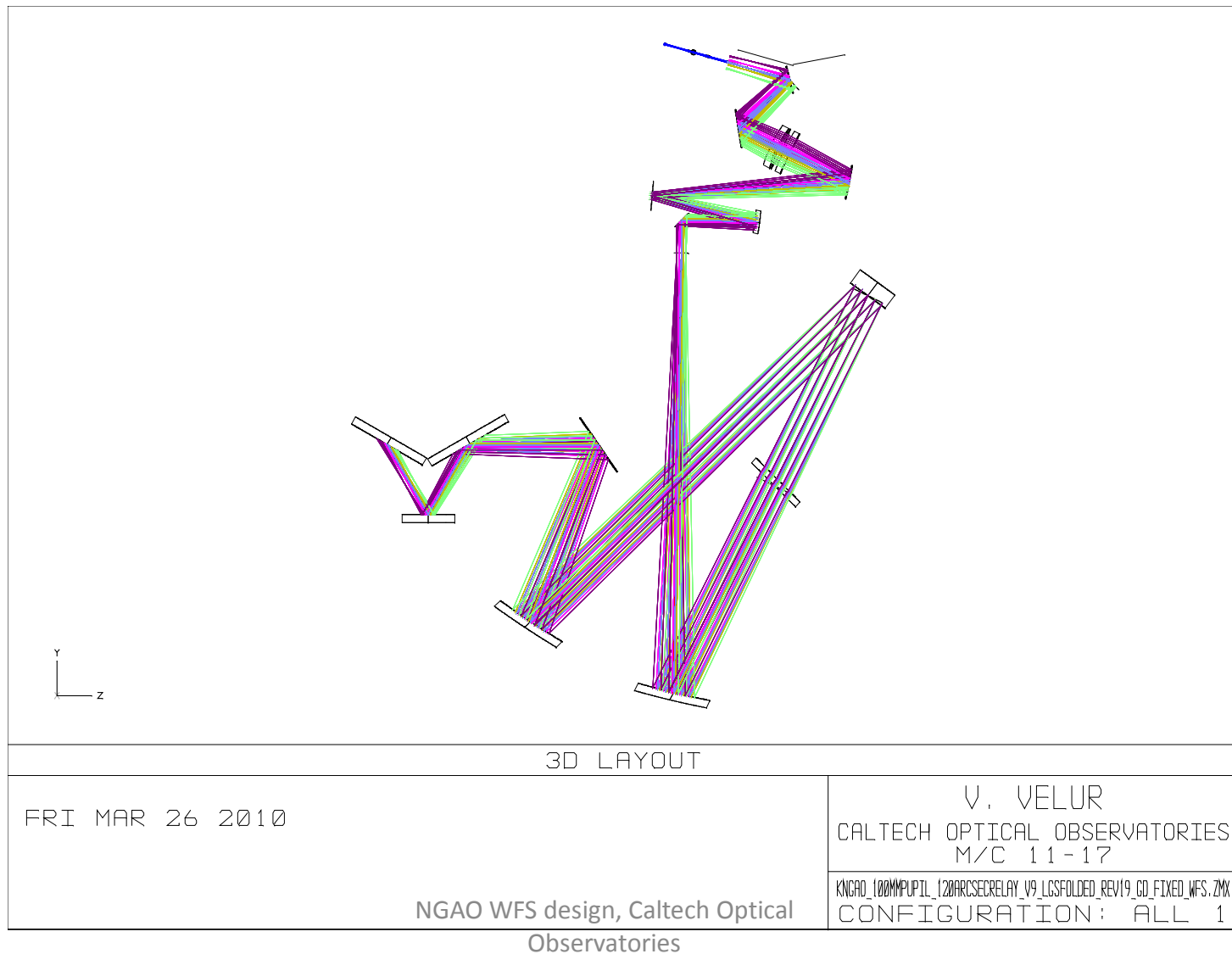
NGAO WFS design, Caltech Optical
Observatories

5x5 NGS WFS layout

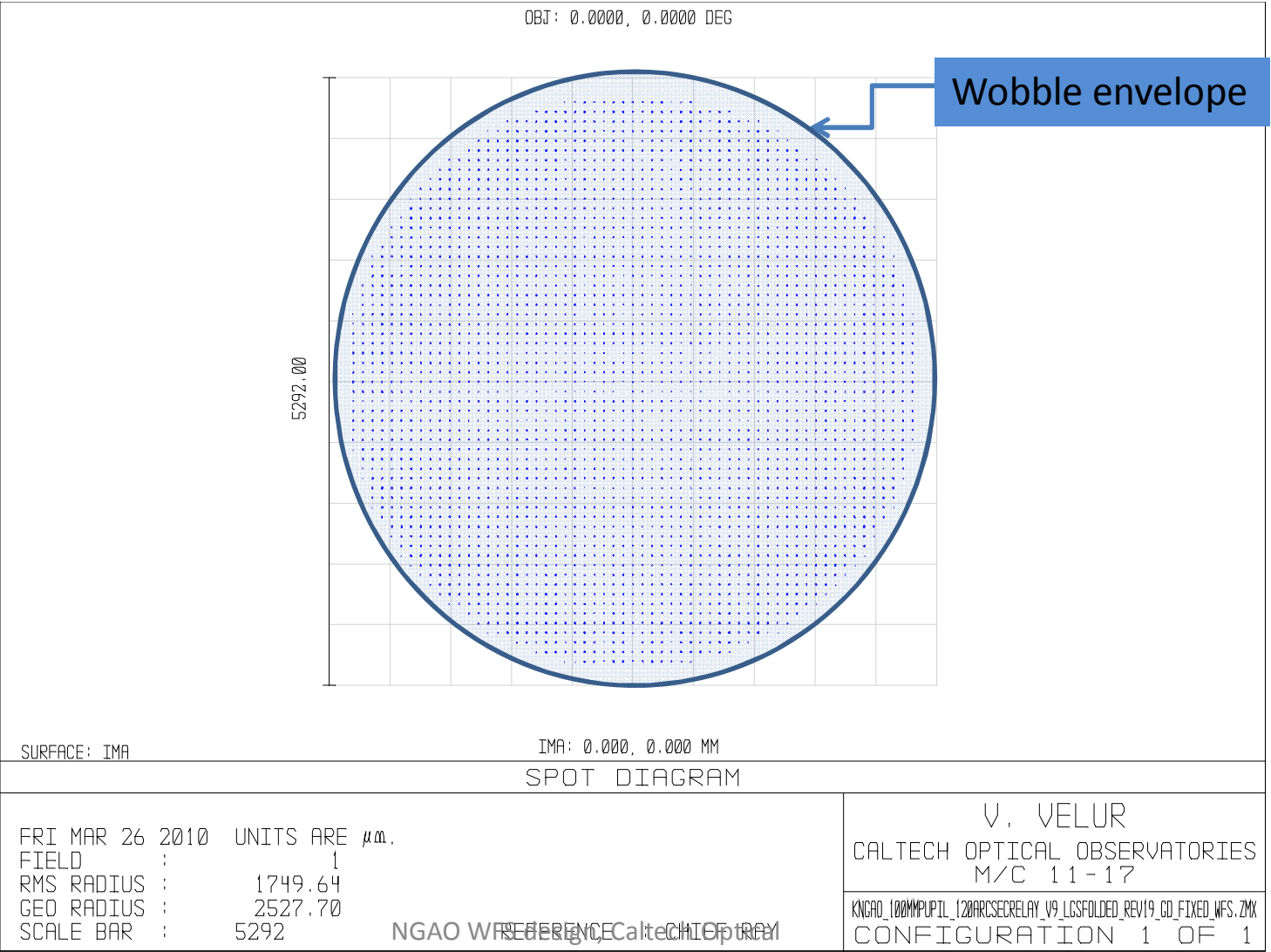
Lens Data Editor													
Edit Solves View Help													
Surf:Type		Comment	Radius	Thickness	Glass	Semi-Diameter	Conic	Par 0(unused)	Par 1(unused)	Par 2(unused)	Par 3(unused)	Par 4(unused)	Par 5(unused)
OBJ	Standard		Infinity	56.502		2.125	0.000						
1*	Standard		83.790	2.000	N-SF5	5.000 U	0.000						
2*	Standard		28.120	5.000	N-BK7	5.000 U	0.000						
3*	Standard	45267	-35.920	56.500		5.000 U	0.000						
4*	Standard	custom lenslet	Infinity	1.500	N-BK7	5.000 U	0.000						
STO	Lens Array		-4.375	8.467		1.581	0.000		5.000	5.000	0.599	0.599	
6	Standard		Infinity	1.000		1.917	0.000						
7*	Standard	custom singlet	-19.621 V	7.000	F2	5.000 U	0.000						
8	Standard		-14.189 V	42.189 V		2.394	0.000						
9*	Standard	custom doublet	257.699 V	4.000	BAFN10	5.000 U	0.000						
10*	Standard		-6.849 V	9.000	SF10	5.000 U	0.000						
11*	Standard		-20.361 V	71.668 V		5.000 U	0.000						
12*	Standard		Infinity	1.500	BK7	5.000 U	0.000						
13	Standard		Infinity	3.000		2.940	0.000						
IMA	Standard		Infinity	-		3.159	0.000						

Reminder: The 5x5 and the 63x63 modes
use the same post-lenslet relay

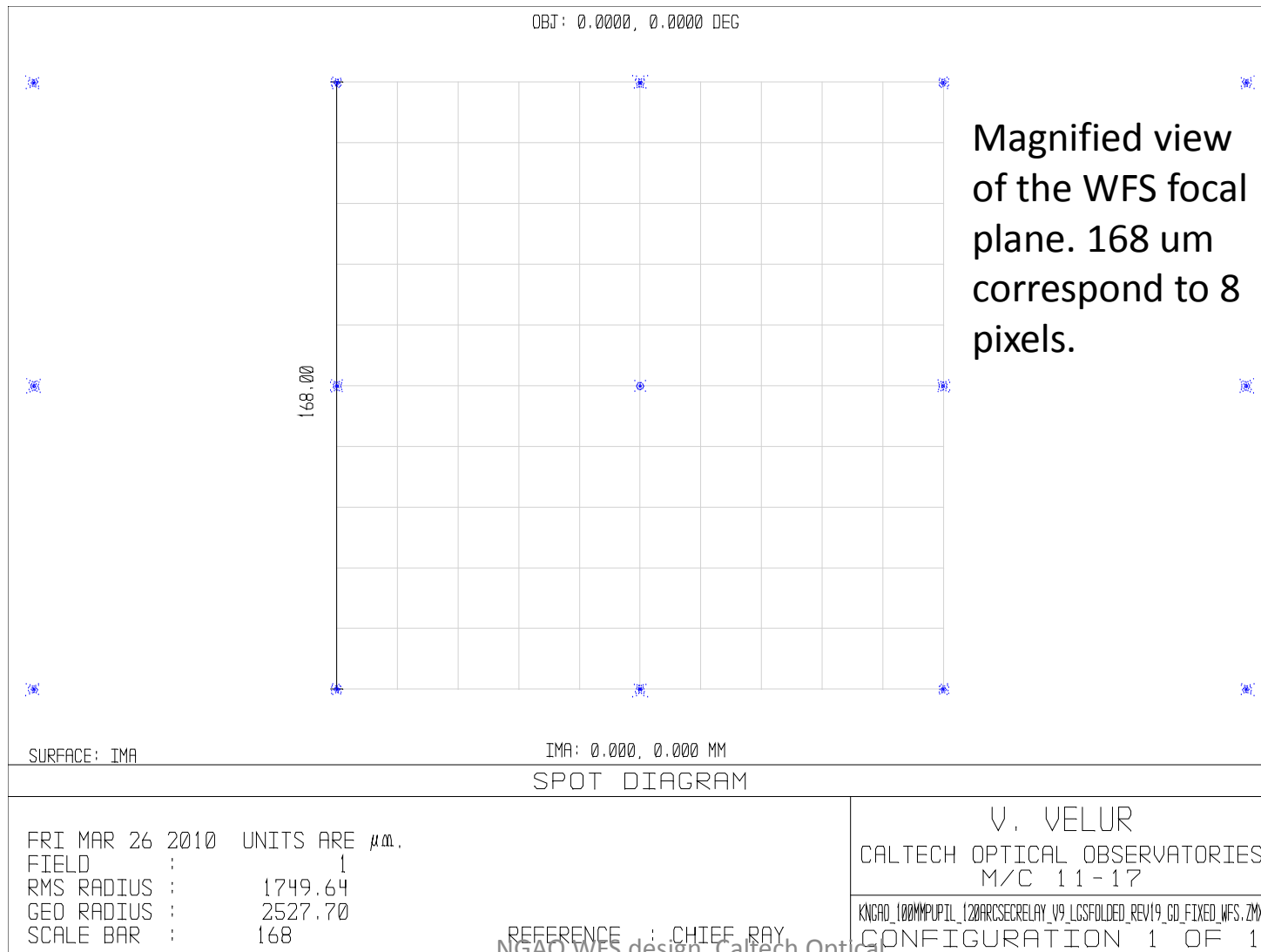
NGS WFS behind the NGAO optical relay



NGS WFS spots showing 59 'lit' sub-apertures

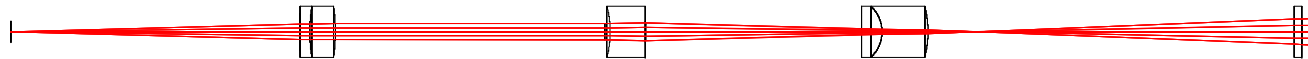


Post lenslet relay – magnified view



NGS WFS operating in pupil imaging mode

- Total relay length = 260 mm
- Components from (left to right) –collimating doublet, field singlet, focusing doublet followed by the window and the detector.
- Wavelength of operation – 500-900 nm



This mode is for alignment only and doesn't have any special requirement.



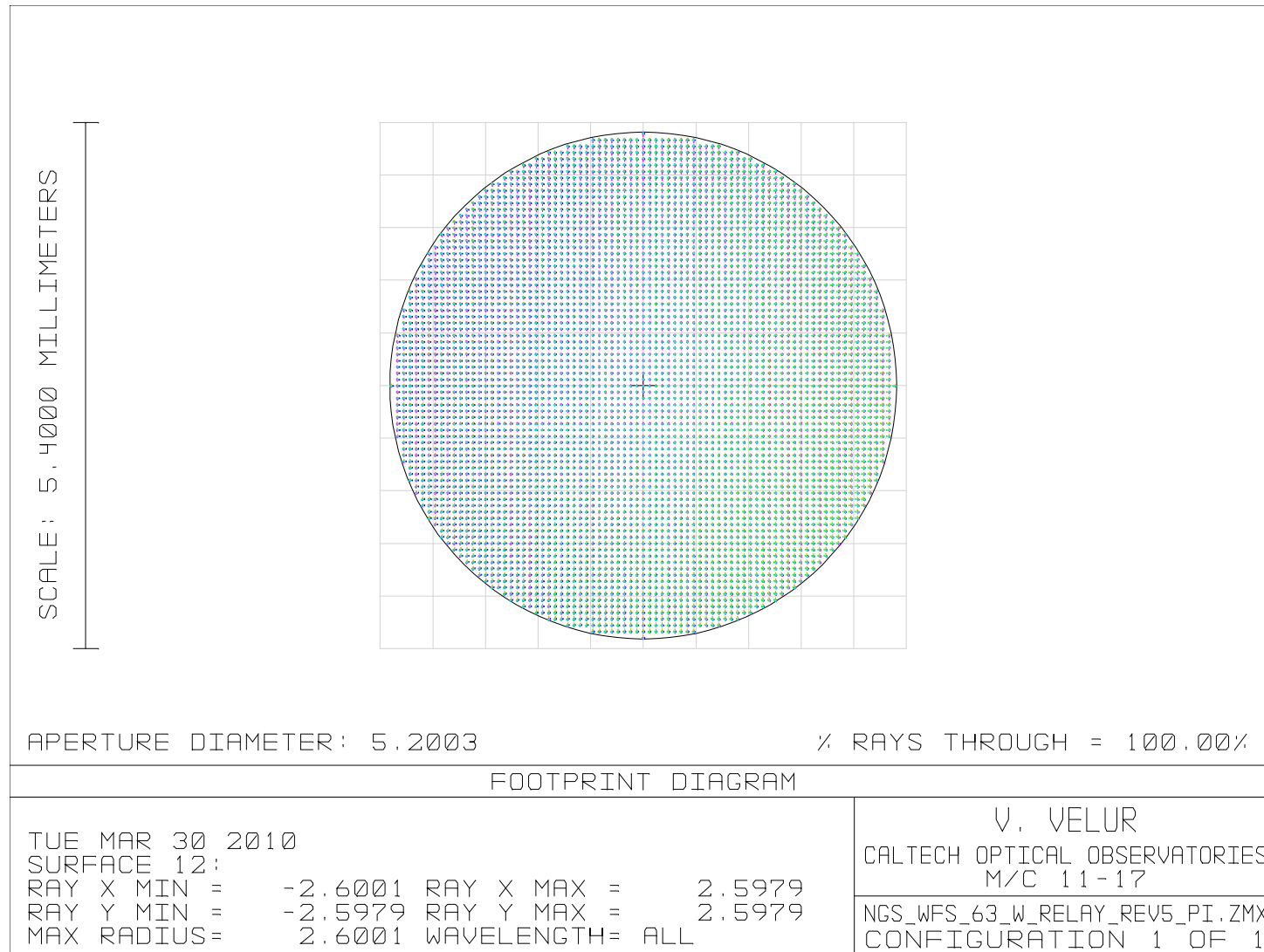
3D LAYOUT

TUE MAR 30 2010

V. VELUR
CALTECH OPTICAL OBSERVATORIES
M/C 11-17

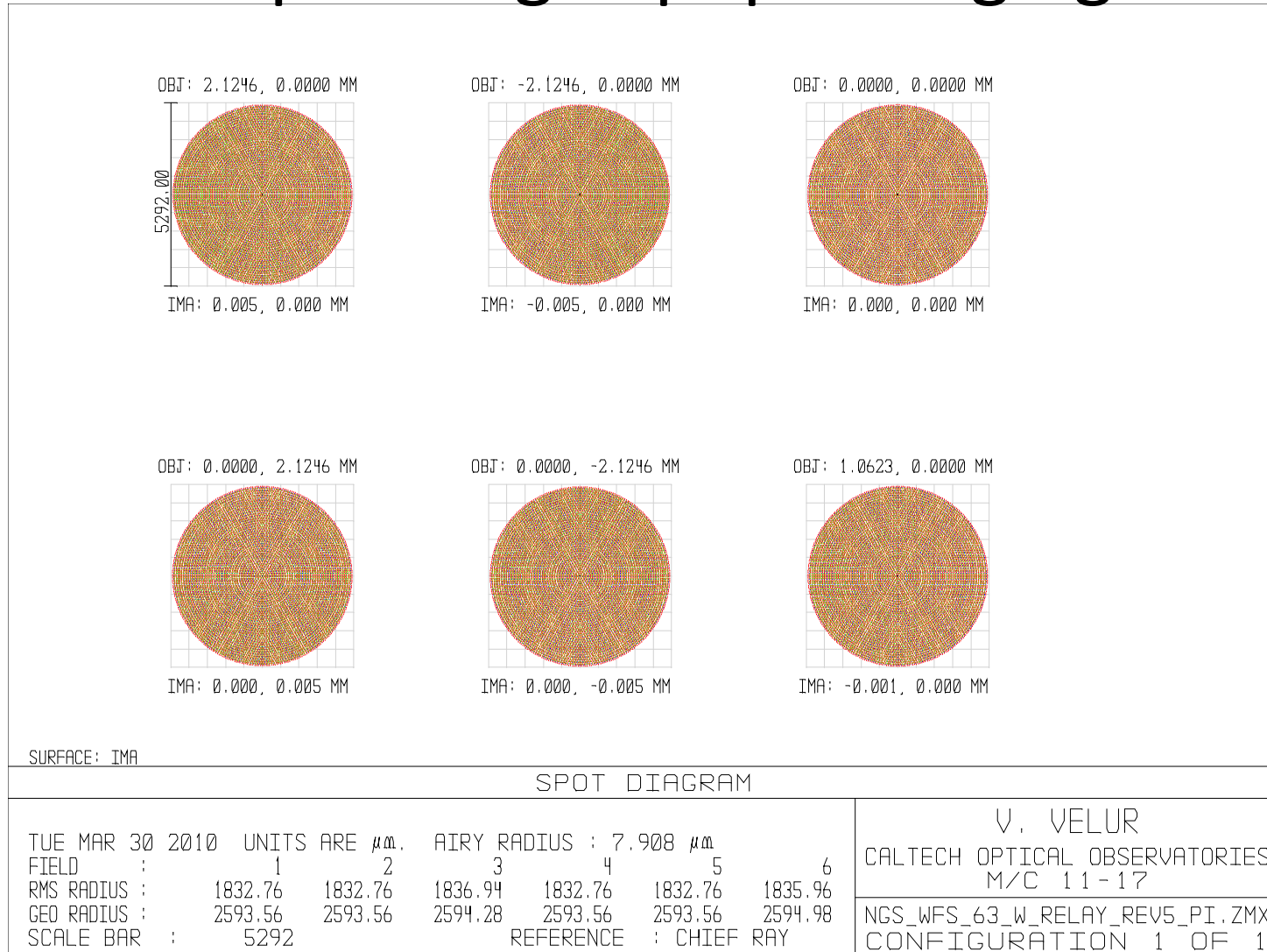
NGS_WFS_63_W_RELAY_REV5_PI.ZMX
CONFIGURATION: ALL 1

NGS WFS operating in pupil imaging mode



NGAO WFS design, Caltech Optical
Observatories

NGS WFS operating in pupil imaging mode



Preliminary tolerance analysis *(using built in tolerancing in Zemax)*

Default Tolerances

Surface Tolerances		Element Tolerances	
☒ Radius	☒ Millimeters: 0.200000 ☐ Fringes: 1.000000	☒ Decenter X	0.200000
☒ Thickness	Millimeters: 0.200000	☒ Decenter Y	0.200000
☒ Decenter X	Millimeters: 0.200000	☒ Tilt X Degrees: 0.200000	
☒ Decenter Y	Millimeters: 0.200000	☒ Tilt Y Degrees: 0.200000	
☒ Tilt (TIR) X	☒ Millimeters: 0.200000 ☐ Degrees: 0.200000		
☒ Tilt (TIR) Y	☒ Millimeters: 0.200000 ☐ Degrees: 0.200000		
☒ S + A Irreg	Frings: 0.200000	☒ Index	0.001000
☐ Zern Irreg	Frings: 0.200000	☒ Abbe %	1.000000

Other Controls

Start At Row: 1 ☒ Use Focus Comp

Test Wavelength: 0.6328

Start At Surface: 1 - custom singlet Stop At Surface: 8

OK Cancel Save Load Reset Help

Since most of Zemax's tools don't work with a lenslet in the optical relay the simplest means to tolerance the WFS is to do it in 2 pieces, viz. post-lenslet relay and the collimator-to-lenslet part.

Tolerance Data Editor

Oper #	Type	Surf	Max#	Min#	Nominal	Min	Max
1 (TEZI)	TEZI	1	3	3	0.000	-1.000E-003	1.000E-003
2 (TEZI)	TEZI	2	3	3	0.000	-1.000E-003	1.000E-003
3 (TEZI)	TEZI	3	3	3	0.000	-1.000E-003	1.000E-003
4 (TEZI)	TEZI	4	3	3	0.000	-1.000E-003	1.000E-003
5 (TEZI)	TEZI	5	3	3	0.000	-1.000E-003	1.000E-003
6 (TEZI)	TEZI	6	3	3	0.000	-1.000E-003	1.000E-003
7 (TEZI)	TEZI	7	3	3	0.000	-1.000E-003	1.000E-003
8 (TEZI)	TEZI	8	3	3	0.000	-1.000E-003	1.000E-003
9 (TOFF)	TOFF	-	-	-	-	-	-

Preliminary tolerance analysis (using built in tolerancing in Zemax)

11: Text Viewer

Update Settings Print Window

Analysis of Tolerances

File : C:\Users\Viswa Velur\Desktop\NGS_WFS_opt_design\ngs_63_relay_rev8_tolerancing.ZMX
Title :
Date : TUE MAR 30 2010

Units are Millimeters.
All changes are computed using linear differences.
Paraxial Focus compensation only.
WARNING: Boundary constraints on compensators will be ignored.

Criterion : RMS Wavefront Error in waves
Mode : Sensitivities
Sampling : 20
Nominal Criterion : 0.01519820
Test Wavelength : 0.5000

Fields: XY Symmetric Object height in Millimeters

#	X-Field	Y-Field	Weight	VDX	VDY	V CX	V CY
1	0.000E+000	0.000E+000	4.000E+000	0.000	0.000	0.000	0.000
2	0.000E+000	1.085E+000	1.000E+000	0.000	0.000	0.000	0.000
3	0.000E+000	-1.085E+000	1.000E+000	0.000	0.000	0.000	0.000
4	0.000E+000	1.550E+000	1.000E+000	0.000	0.000	0.000	0.000
5	0.000E+000	-1.550E+000	1.000E+000	0.000	0.000	0.000	0.000
6	1.085E+000	0.000E+000	1.000E+000	0.000	0.000	0.000	0.000
7	-1.085E+000	0.000E+000	1.000E+000	0.000	0.000	0.000	0.000
8	1.550E+000	0.000E+000	1.000E+000	0.000	0.000	0.000	0.000
9	-1.550E+000	0.000E+000	1.000E+000	0.000	0.000	0.000	0.000

Sensitivity Analysis:

Type	Value	Minimum	Maximum	Change
TEZI 1	-0.001000000	0.01520071	2.5172E-006	0.001000000
TEZI 2	-0.001000000	0.01523119	3.2991E-005	0.001000000
TEZI 3	-0.001000000	0.01525502	5.6821E-005	0.001000000
TEZI 4	-0.001000000	0.01524933	5.1136E-005	0.001000000
TEZI 5	-0.001000000	0.01559543	0.00039723	0.001000000
TEZI 6	-0.001000000	0.01519831	1.1190E-007	0.001000000
TEZI 7	-0.001000000	0.01519851	3.1115E-007	0.001000000
TEZI 8	-0.001000000	0.01519851	3.1842E-007	0.001000000

Worst offenders:

Type	Value	Criterion	Change
TEZI 5	0.001000000	0.01559543	0.00039723
TEZI 5	-0.001000000	0.01559543	0.00039723
TEZI 3	-0.001000000	0.01525502	5.6821E-005
TEZI 3	0.001000000	0.01525502	5.6821E-005
TEZI 4	0.001000000	0.01524933	5.1136E-005
TEZI 4	-0.001000000	0.01524933	5.1136E-005
TEZI 2	-0.001000000	0.01523119	3.2991E-005
TEZI 2	0.001000000	0.01523119	3.2991E-005
TEZI 1	0.001000000	0.01520071	2.5172E-006
TEZI 1	-0.001000000	0.01520071	2.5172E-006

Estimated Performance Changes based upon Root-Sum-Square method:

Nominal RMS Wavefront	: 0.01519820
Estimated change	: 0.00040587
Estimated RMS Wavefront	: 0.01560407

Compensator Statistics:

Change in back focus:	: 0.000000
Minimum	: 0.000000
Maximum	: 0.000000
Mean	: 0.000000
Standard Deviation	: 0.000000

Monte Carlo Analysis:
Number of trials: 20
Initial Statistics: Parabolic Distribution

Trial	Criterion	Change
1	0.01569850	0.00050030
2	0.01574422	0.00054602
3	0.01528623	8.8031E-005
4	0.01578568	0.00058748

11: Text Viewer

Update Settings Print Window

TEZI 6	-0.001000000	0.01519831	1.1190E-007	0.001000000	0.01519831	1.1190E-007
TEZI 7	-0.001000000	0.01519851	3.1115E-007	0.001000000	0.01519851	3.1115E-007
TEZI 8	-0.001000000	0.01519851	3.1842E-007	0.001000000	0.01519851	3.1842E-007

Worst offenders:

Type	Value	Criterion	Change
TEZI 5	0.001000000	0.01559543	0.00039723
TEZI 5	-0.001000000	0.01559543	0.00039723
TEZI 3	-0.001000000	0.01525502	5.6821E-005
TEZI 3	0.001000000	0.01525502	5.6821E-005
TEZI 4	0.001000000	0.01524933	5.1136E-005
TEZI 4	-0.001000000	0.01524933	5.1136E-005
TEZI 2	-0.001000000	0.01523119	3.2991E-005
TEZI 2	0.001000000	0.01523119	3.2991E-005
TEZI 1	0.001000000	0.01520071	2.5172E-006
TEZI 1	-0.001000000	0.01520071	2.5172E-006

Estimated Performance Changes based upon Root-Sum-Square method:

Nominal RMS Wavefront	: 0.01519820
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Compensator Statistics:

Change in back focus:	: 0.000000
Minimum	: 0.000000
Maximum	: 0.000000
Mean	: 0.000000
Standard Deviation	: 0.000000

Number of trials: 20
Initial Statistics: Parabolic Distribution

Trial	Criterion	Change
1	0.01569850	0.00050030
2	0.01574422	0.00054602
3	0.01528623	8.8031E-005
4	0.01578568	0.00058748
5	0.01549968	0.00030149
6	0.01522484	2.6643E-005
7	0.01529687	9.8674E-005
8	0.01556191	0.00036371
9	0.01546792	0.00026972
10	0.01522266	2.4461E-005
11	0.01546792	0.00026972
12	0.01531412	0.00011593
13	0.01617162	0.00097343
14	0.01567164	0.00047344
15	0.01525219	5.3991E-005
16	0.01578669	0.00058850
17	0.01553688	0.00033868
18	0.01523008	3.1881E-005
19	0.01571600	0.00051780
20	0.01615611	0.00095791

Number of traceable Monte Carlo files generated: 20

Nominal	0.01519820
Best	0.01522266
Worst	0.01617162
Mean	0.01555459
Std Dev	0.00028077

Compensator Statistics:

Change in back focus:	: 0.000000
Minimum	: 0.000000
Maximum	: 0.000000
Mean	: 0.000000
Standard Deviation	: 0.000000

90% < 0.01597140
80% < 0.01576495
50% < 0.01551828
20% < 0.01526921
10% < 0.01522746

End of Run.

Nothing remarkable here!

Summary of work done by WFS team

- Contributed to systems engineering and requirements ratification process
- Designed a NGS feed using a refractive triplet to solve NGAO's packaging problem while delivering a f/20 beam to the NGS sensor and analyzed its performance
- Designed a compact WFS that works in 63x63, 5x5 and pupil imaging modes.
- Quantified the effects of color and distortion in mapping the HODM pupil to the lenslet.
- Did very preliminary tolerancing for the WFS.
- Made a list of outstanding issues and analysis for the DD phase.
- Built a compliance matrix and risk register.

Other issues

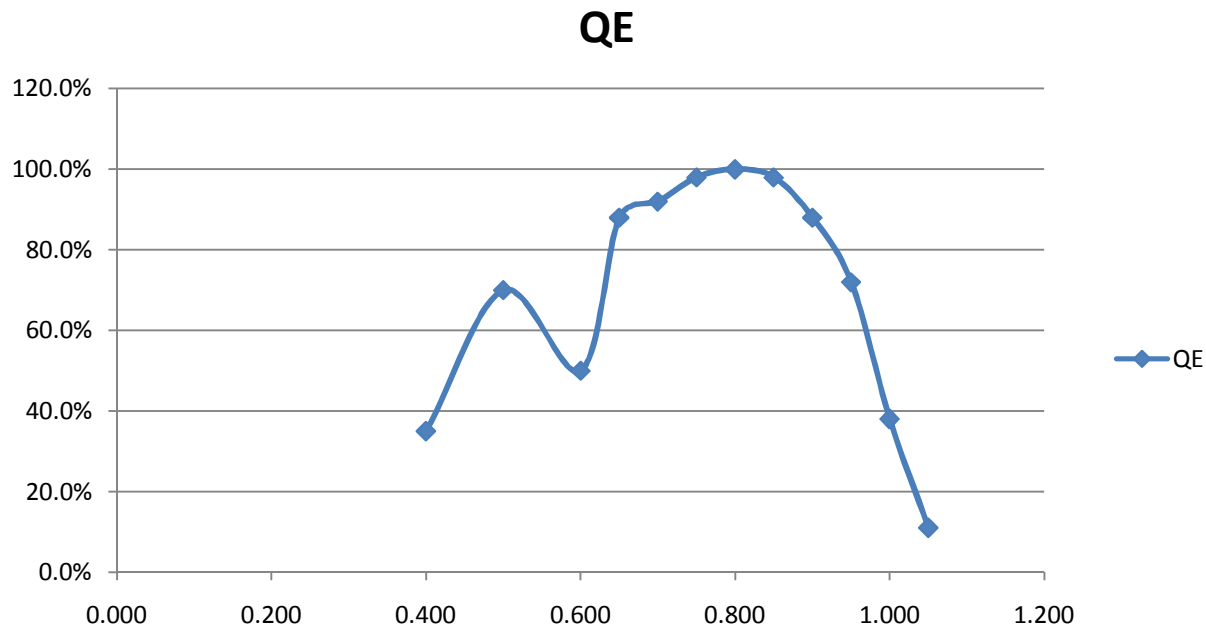
- Thermal issues
 - -15C operation (does this matter?)
- Stray light
 - Baffles / filters (unnecessary?)
 - Ghosts (usually not an issue of NGS WFS, but for PDR mention for completeness)

Detector choice and performance

- NGAO envisages the use of 256x256 pixel CCID74 detector with 21 μm pixels that is under development at Lincoln Labs for wavefront sensing.

Predicted Quantum efficiency*

(based on 75 micron substrate, Bodacious Black AR coating^ on Pan-STARRS CCID-58)



^ - LL plans to use a different AR coating that will result in ~90% QE at 589 nm

*-Source - S. Adkins, Pvt. Comm.

Read noise *[predicted and measured]*

