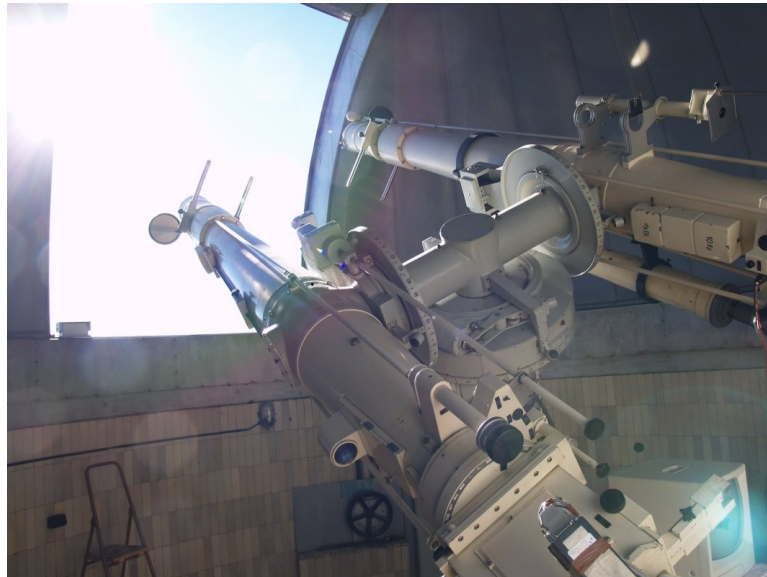


Zeiss Lens Replacement Analysis for Coronagraphs at the Lomnický štít Observatory

Phil Oakley
2/27/2014



Analysis Summary

- Original coronagraph lenses are several decades old and have small imperfections from use and cleaning
- Zeiss is able to replace the lenses, but can only manufacture lenses with small differences to existing lenses
- How will this effect the performance of the instruments?

Summary of Lens Differences

Lens	Material	Front Radius of Curvature [mm]	Rear Radius of Curvature [mm]	Calculated Focal Length [mm at 1083 nm]
Original Objective Lens	BK7	1710.0	-17000.0	3068.217
Replacement Objective Lens	N-BK7	1709.9	-17013.0	3068.269
Original Field Lens	BK7	199.49	-390.00	260.630
Replacement Field Lens	N-BK7	199.53	-389.90	260.642

The focal length shifts are on order 10s of microns while the *estimated* depth of focus is 100s of microns.

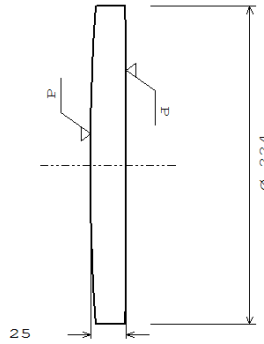
Summary of Lens Differences (Zemax Lens Data Editor)

Surf:	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
*	Standard		Infinity	Infinity		Infinity	0.0000000
*	Standard	Objective	1710.000000	25.0000000	BK7	112.0000000 U	0.0000000
2*	Standard		-17000.0000	2974.454469		112.0000000 U	0.0000000
3*	Standard	Focus	Infinity	5.8500000		22.8241385	0.0000000
4*	Standard	Field Lens	199.4900000	10.7200000	BK7	29.5000000 U	0.0000000
5*	Standard		-390.000000	167.7000000		29.5000000 U	0.0000000

New Replacement Lenses

Surf:	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
*	Standard		Infinity	Infinity		Infinity	0.0000000
*	Standard	Objective	1709.900000	25.0000000	N-BK7	112.0000000 U	0.0000000
2*	Standard		-17013.0000	2974.454469		112.0000000 U	0.0000000
3*	Standard	Focus	Infinity	5.8500000		22.8225352	0.0000000
4*	Standard	Field Lens	199.5300000	10.7200000	N-BK7	29.5000000 U	0.0000000
5*	Standard		-389.900000	167.7000000		29.5000000 U	0.0000000

Objective Lens

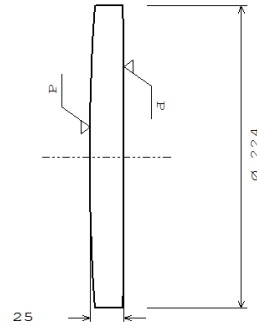


Original
Objective Lens

Dimensions in Millimeters

Left Surface	Material	Right Surface
R 1710 CX Ø _E 224 ⊙ 3/ 4/ - 5/ - 6/ -	GLASS: BK7 N _d = 1.516800 V _d = 64.17 0/ - 1/ - 2/ -	R 17000 CX Ø _E 224 ⊙ 3/ 4/ - 5/ - 6/ -

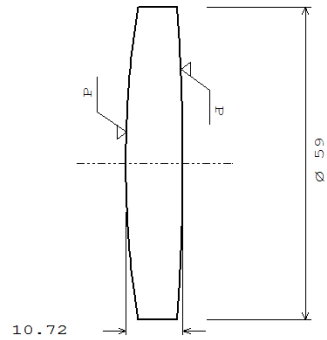
Replacement
Objective Lens



Dimensions in Millimeters

Left Surface	Material	Right Surface
R 1709.9 CX Ø _E 224 ⊙ 3/ 4/ - 5/ - 6/ -	GLASS: N-BK7 N _d = 1.516800 V _d = 64.17 0/ - 1/ - 2/ -	R 17013 CX Ø _E 224 ⊙ 3/ 4/ - 5/ - 6/ -

Field Lens



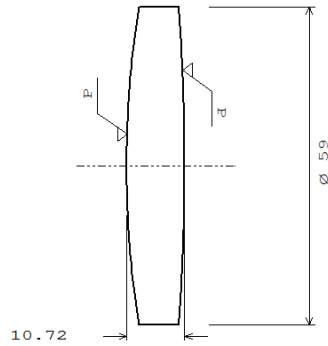
Original Field Lens



Dimensions in Millimeters

Left Surface	Material	Right Surface
R 199.49 CX Ø _e 59 ⊙ 3/ - 4/ - 5/ - 6/ -	GLASS: BK7 N _d = 1.516800 V _d = 64.17 0/ - 1/ - 2/ -	R 390 CX Ø _e 59 ⊙ 3/ - 4/ - 5/ - 6/ -

Replacement Field Lens



Dimensions in Millimeters

Left Surface	Material	Right Surface
R 199.53 CX Ø _e 59 ⊙ 3/ - 4/ - 5/ - 6/ -	GLASS: N-BK7 N _d = 1.516800 V _d = 64.17 0/ - 1/ - 2/ -	R 389.9 CX Ø _e 59 ⊙ 3/ - 4/ - 5/ - 6/ -

Prime Focus Quality Comparison

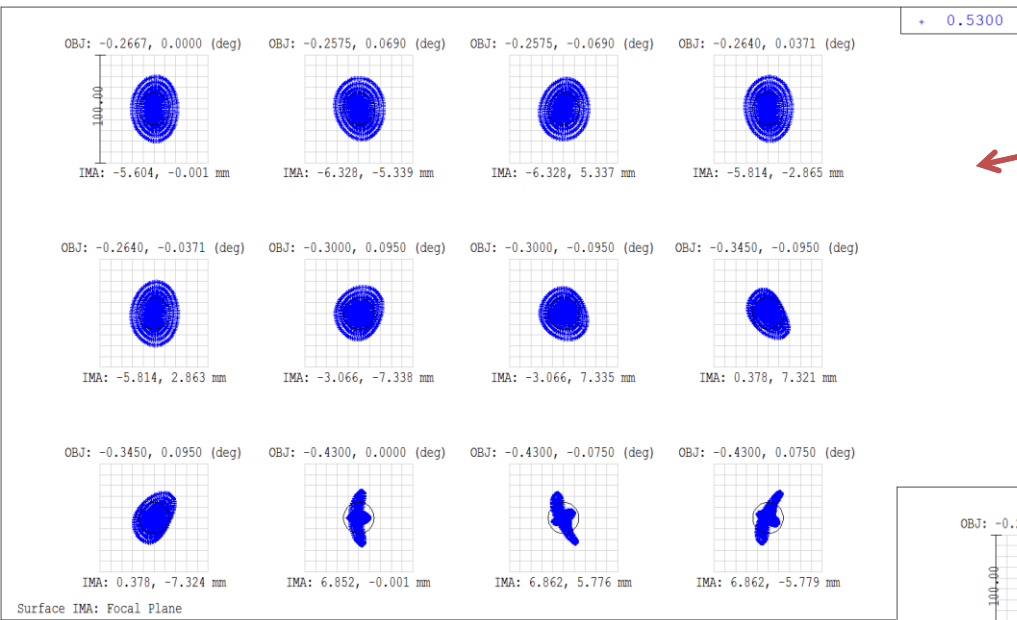


- **Blue** = Original Objective Lens
- **Green** = Replacement Objective Lens
- Summary = no significant loss of quality

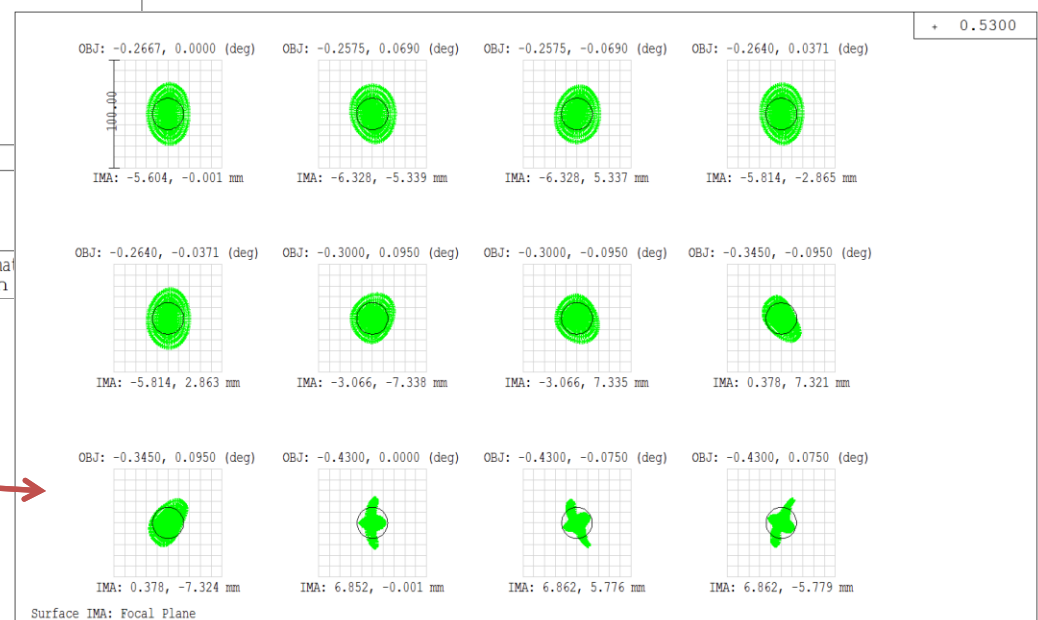


Configuration Matrix Spot Diagram		
PDSS 2/27/2014	Units are μm .	Airy Radius: 9.661 μm
Scale bar : 100	Reference : Chief Ray	PDSS 11 1 2013 achromatic FINAL.zmx Configuration: All 2

PDSS Image Comparison (530 nm)



Original Lenses



Replacement Lenses



Spot Diagram

PDSS
2/27/2014 Units are μm .

Field	1	2	3	4	5	6	7	8	9	10	11	12
RMS radius :	12.374	12.232	12.089	12.330	12.249	10.709	10.529	9.538	9.497	9.290	9.503	9.561
GD radius :	25.893	28.468	28.114	25.450	25.319	25.894	25.523	25.735	26.043	25.146	26.305	26.461

Airy Radius: 14.52 μm

Reference : Centroid

PDSS 11 1 2013 achromatic Configuration

Spot Diagram

PDSS
2/27/2014 Units are μm .

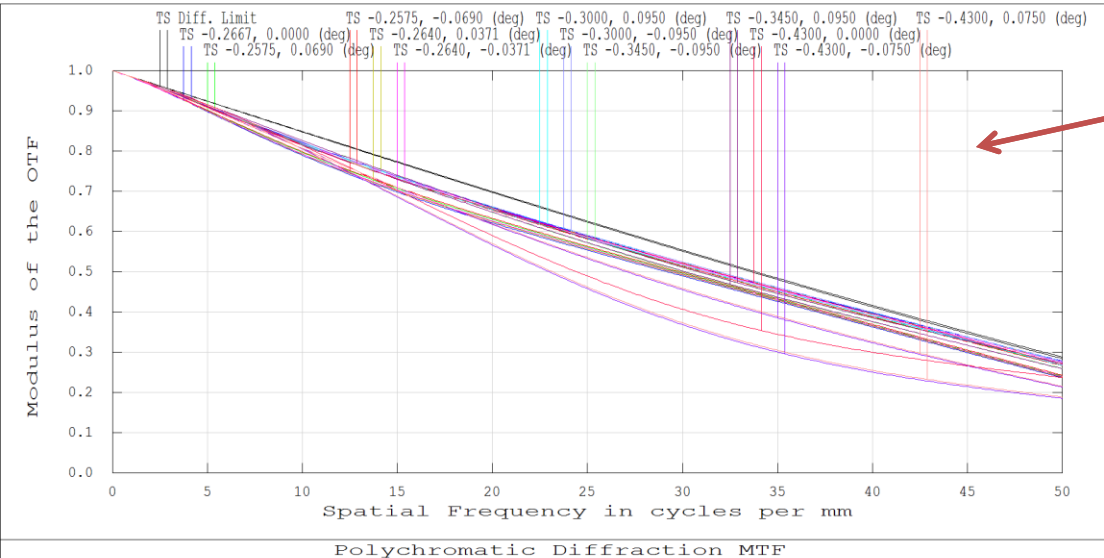
Field	1	2	3	4	5	6	7	8	9	10	11	12
RMS radius :	11.117	10.962	10.831	11.067	10.992	9.539	9.382	8.593	8.720	8.881	9.198	9.222
GD radius :	23.511	26.079	25.735	27.072	26.945	23.493	23.122	23.349	23.656	22.779	23.529	24.004

Airy Radius: 14.49 μm

Reference : Centroid

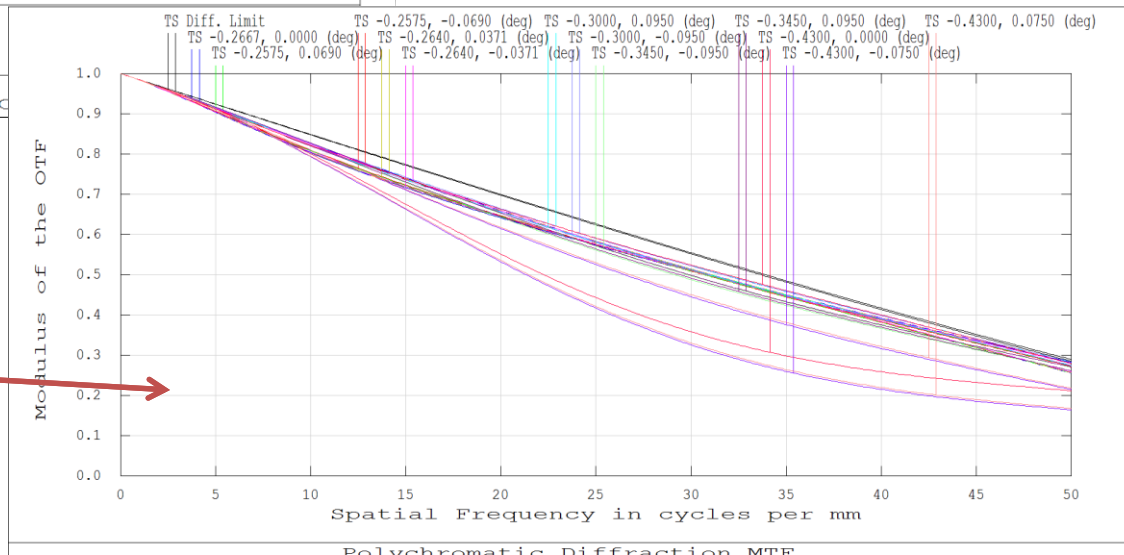
PDSS 11 1 2013 achromatic FINAL.zmx Configuration 2 of 11

PDSS Image Comparison (530 nm)



Original Lenses

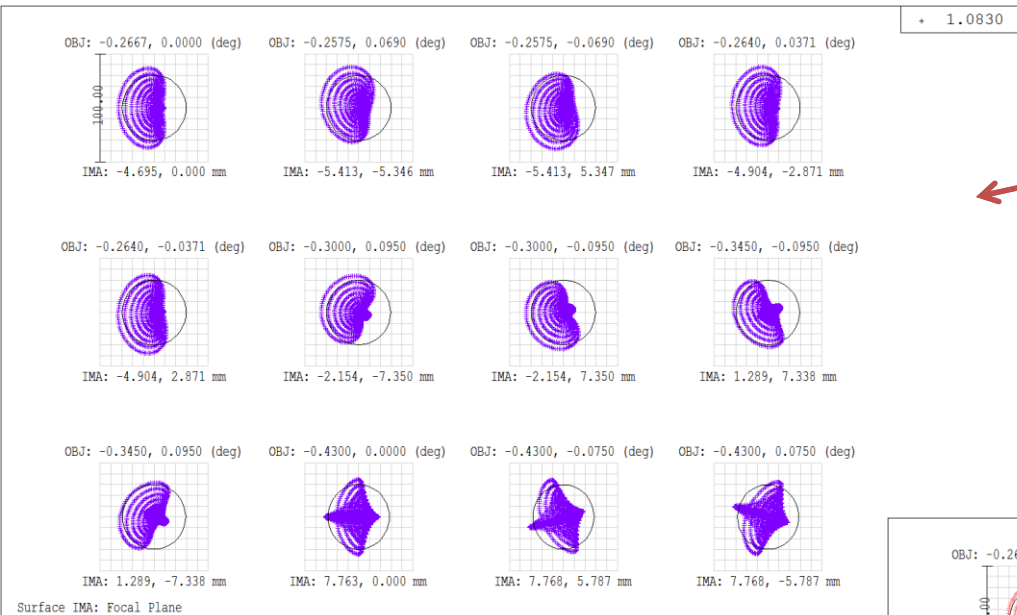
PDSS
 3/4/2014
 Data for 0.5300 to 0.5300 μm .
 Surface: Image (Focal Plane)



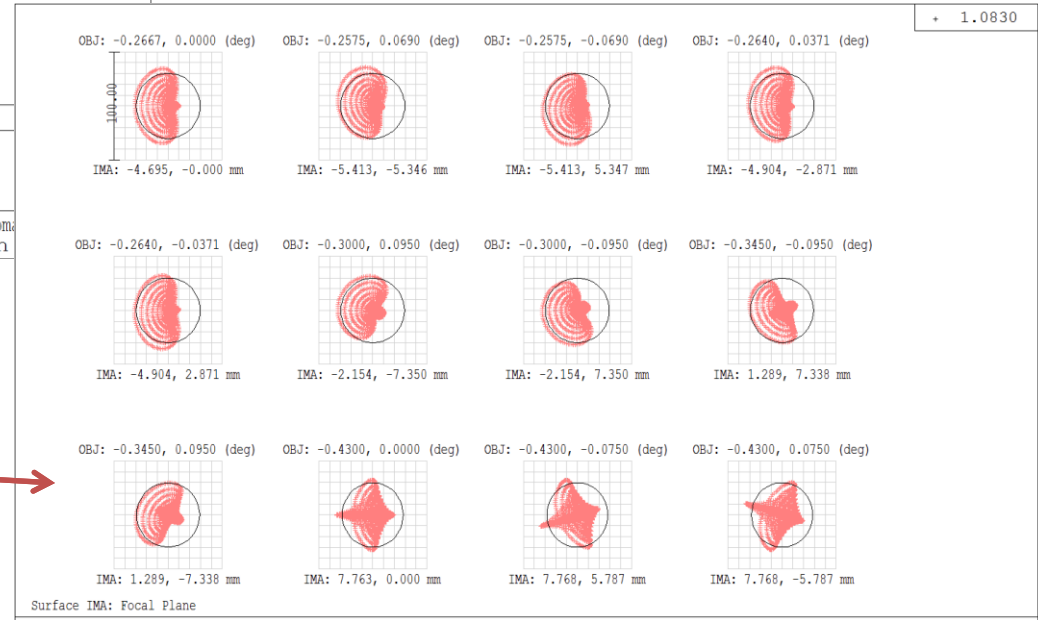
Replacement Lenses

PDSS
 3/4/2014
 Data for 0.5300 to 0.5300 μm .
 Surface: Image (Focal Plane)

PDSS Image Comparison (1083 nm)



Original Lenses



Replacement Lenses

Spot Diagram

PDSS
2/27/2014 Units are μm . Airy Radius: 29.88 μm

Field	1	2	3	4	5	6	7	8	9	10	11	12
RMS radius :	15.061	14.647	14.647	14.907	14.907	13.241	13.241	13.096	13.096	15.575	16.407	16.407
GDQ radius :	37.522	39.264	39.264	38.626	38.626	34.846	34.846	34.477	34.477	34.479	36.009	36.009
Scale bar :	100											

Reference : Centroid

PDSS 11 1 2013 achromat Configuration

Spot Diagram

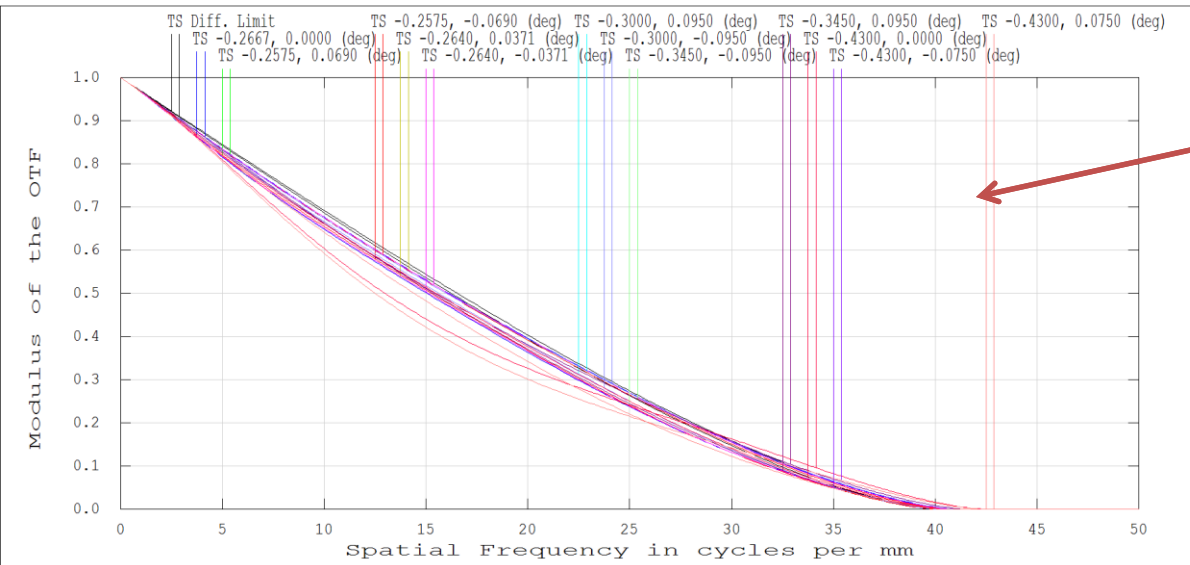
PDSS
2/27/2014 Units are μm . Airy Radius: 29.82 μm

Field	1	2	3	4	5	6	7	8	9	10	11	12
RMS radius :	13.868	13.431	13.430	13.707	13.707	12.212	12.212	12.304	12.304	15.879	16.344	16.344
GDQ radius :	35.239	36.572	36.572	36.339	36.339	32.568	32.568	32.222	32.222	33.358	35.102	35.102
Scale bar :	100											

Reference : Centroid

PDSS 11 1 2013 achromatic FINAL.zmx Configuration 12 of 12

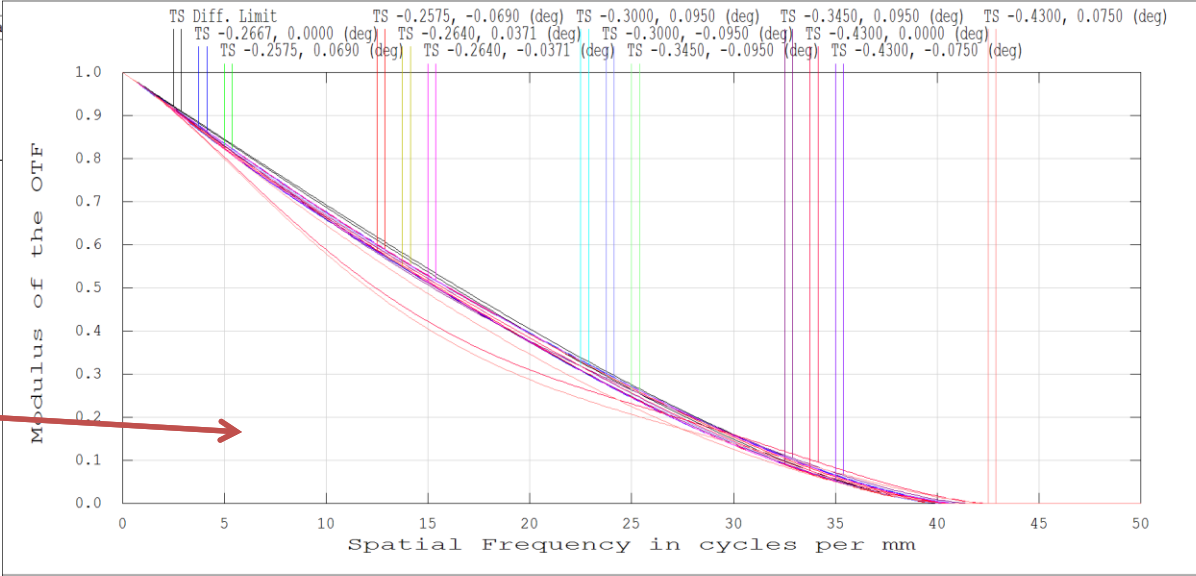
PDSS Image Comparison (1083 nm)



Original Lenses

Polychromatic Diffraction MTF

PDSS
 3/4/2014
 Data for 1.0830 to 1.0830 μm .
 Surface: Image (Focal Plane)



Replacement Lenses

Polychromatic Diffraction MTF

PDSS
 3/4/2014
 Data for 1.0830 to 1.0830 μm .
 Surface: Image (Focal Plane)

PDSS 11 1 2013 achromatic FINAL Lens Replacement Analysis.ZMK
 Configuration 12 of 12

Unknowns?

- AR Coatings
- Clear Aperture
- Surface Runout (wedge)
- Surface irregularity
- Index uncertainty
- Radii uncertainty
- If these tolerances are worse than the original lenses then performance loss might become more significant

Summary

- The new replacement lens cause changes in focal lengths of 10s of microns
- The PDSS optical design can tolerate 10s of microns of defocus.
- PDSS Instrument maintains image quality without any adjustments given new lenses (assuming optimal lenses)
- New lens unknowns listed on previous slide could effect performance if delivered lens differs from optimal (example – if new lenses have very loose tolerances on parameters). PDSS optical design is generally forgiving, so this is unlikely.