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Wide Field Corrector
On-sky Image Quality Prediction

March 18, 2015 (original)
April 3, 2015 (revised)
April 10, 2015 (revised)

Outline

- HET Image quality error budget & Other requirements
- Current knowledge of WFC mirror prescription & alignment state
- Prediction of the HET on-sky image quality & other requirements
- Summary

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HET Image Quality Budget in EE50 [arcsec]

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Contribution	Radial Field Position				
	0 arcmin	2.7 arcmin	5.4 arcmin	8.1 arcmin	11.0 arcmin
WFC Nominal design	0.10	0.09	0.07	0.13	0.24
WFC Mirror prescription	0.10	0.09	0.07	0.08	0.12
WFC Alignment	0.02	0.02	0.08	0.11	0.11
WFC assembly	0.00	0.01	0.02	0.03	0.03
Mirror polishing/figuring	0.06	0.07	0.07	0.07	0.04
WFC Thermal effect	0.10	0.10	0.10	0.10	0.10
WFC internal mirror motion	0.00	0.00	0.02	0.01	0.03
WFC Windows / ADC	0.03	0.03	0.05	0.07	0.08
HET M1	0.45	0.45	0.45	0.45	0.45
HET Tracking error	0.34	0.34	0.35	0.36	0.36
HET Facility	0.2	0.2	0.2	0.2	0.2
HET Seeing	1.0	1.0	1.0	1.0	1.0
RSS	**1.18**	**1.18**	**1.18**	**1.20**	**1.22**
RSS without seeing	**0.62**	**0.62**	**0.62**	**0.66**	**0.69**
HET Specification	**1.19**	**1.23**	**1.27**	**1.32**	**1.38**

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HET on-sky performance prediction

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Contribution	Radial Field Position				
	0 arcmin	2.7 arcmin	5.4 arcmin	8.1 arcmin	11.0 arcmin
WFC Nominal design	0.10	0.09	0.07	0.13	0.24
WFC Mirror prescription	0.10	0.09	0.07	0.08	0.12
WFC Alignment	0.02	0.02	0.08	0.11	0.11

These first three contributions are modeled in Zemax based on the current knowledge of

- The WFC mirror prescriptions
- The WFC alignment state due to the 6 possible cases from the conjugate test

The rest of the contributions (including 1” seeing) are summed to the first three in RSS.

Then, the resultant EE50 across field has been compared to the HET specification.

HET Specification	1.19	1.23	1.27	1.32	1.38

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List of other requirements

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Metric	Requirement	Expectation	PASS/FAIL	Unit
Effective focal length	36450 – 36550			mm
Focal ratio*	3.645 – 3.655			--
Max. marginal ray angle	7.863 – 7.884			degrees
Max. telecentric angle	0.0 – 0.01			degrees
Max. distortion	0.0 – 1			%
Un-vignetted portion of beam	> 80 on-axis > 64 at edge			%

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* Focal ratio is the paraxial focal ratio given by EFL / 10m pupil at on-axis.

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Current knowledge of WFC Mirror Prescription

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Parameter	M4	M5	M2	M3	ACP
Radius of Curvature (±2σ) [mm]	376.604 (0.045)	742.343 (0.040)	2620.719 (0.05)	2032.675 (0.05)	--
Conic constant (±2σ)	-2.09847 (0.0004)	-0.2672 (0.00006)	0.6628 (0.0007)	-7.7137 (0.0008)	--
A2 [mm/ mm^2]	--	--	--	--	-7.7179×10^{-6}
A4 [mm/ mm^4]	--	--	--	--	-6.5514×10^{-11}
A6 [mm/ mm^6]	--	1.5875×10^{-19}	--	-8.2493×10^{-17}	--
A8 [mm/ mm^8]	--	6.4401×10^{-26}	--	8.4345×10^{-23}	--
A10 [mm/ mm^10]	--	--	--	-3.8661×10^{-29}	--

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Possible range of WFC System Alignment

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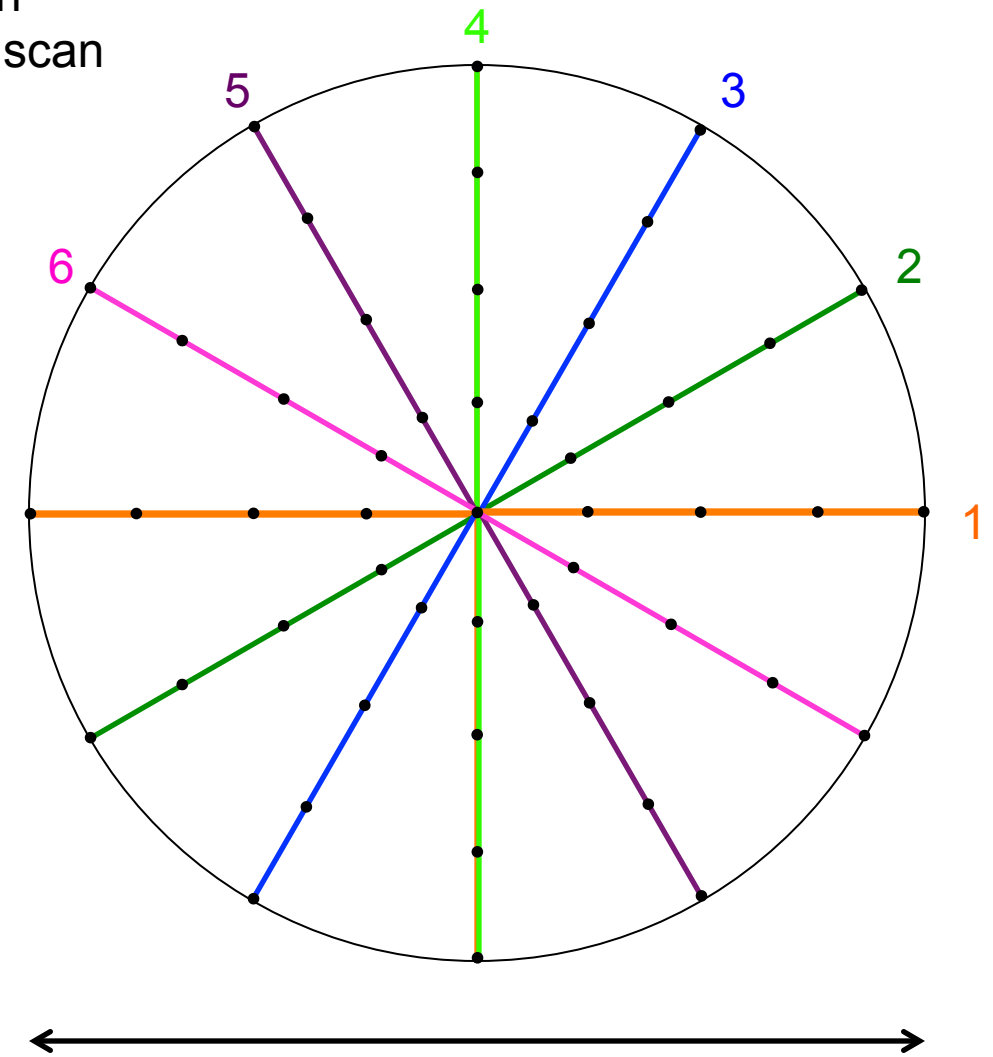
CASE	M4					M5					M2			M3		
	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	DZ (±2σ) [μm]	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	DZ (±2σ) [μm]	DX/ DY (±2σ) [μm]	Rx/ Ry (±2σ) [μrad]	DZ (±2σ) [μm]	DX/ DY (±2σ) [μm]	Rx/ Ry (±2σ) [μrad]	DZ (±2σ) [μm]
1	**-117.9** 27.40	**-1.7** 26.80	**-95** 54.80	**-29.1** 55.30	**0.0** (16.7)	**-188.1** 48.80	**18.1** 48.20	**19.4** 68.80	**127.5** 68.50	**3.0** (16.7)	**within** (25.6)	**within** (76.7)[1] (23.3)[2]	**6.0** (16.7)	**within** (25.6)	**within** (83.3)[1] (23.3)[2]	**0.0** (16.7)
2	**-13.4** 6.2	**-2.6** 6.4	**-2.6** 54.6	**174.9** 54.2		**22.3** 16.2	**4.9** 15.8	**29.2** 52.4	**-14.3** 52.4							
3	**0.2** 6.2	**-7.7** 6.4	**-97.9** 53.3	**-84.1** 53.5		**13.5** 16.2	**7.9** 15.8	**9.5** 52.4	**-66.8** 52.3							
4	**2.9** 6.2	**-7.7** 6.4	**-100.4** 54.6	**-136** 54.5		**11.7** 16.2	**8.1** 15.8	**9.1** 52.5	**-77.3** 52.3							
5	**-49.2** 26.3	**-23.2** 25.5	**-67.8** 54	**58.4** 54.3		**-55.7** 46.4	**-23.6** 45.5	**-12.1** 67.7	**28.8** 67.5							
6	**-5.9** 6.1	**-5.4** 6.3	**-55.9** 51.4	**30.1** 51.2		**17.3** 16.2	**6.6** 15.8	**18.2** 52.3	**-43.5** 52.2							

[1]: Uncertainty in knowing the absolute values of Rx/Ry of M2/M3.
[2]: Uncertainty in knowing the relative value of Rx/Ry between M2 and M3.

Field locations

6 scans across azimuth
9 field point along one scan



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As-designed WFC spot diagram

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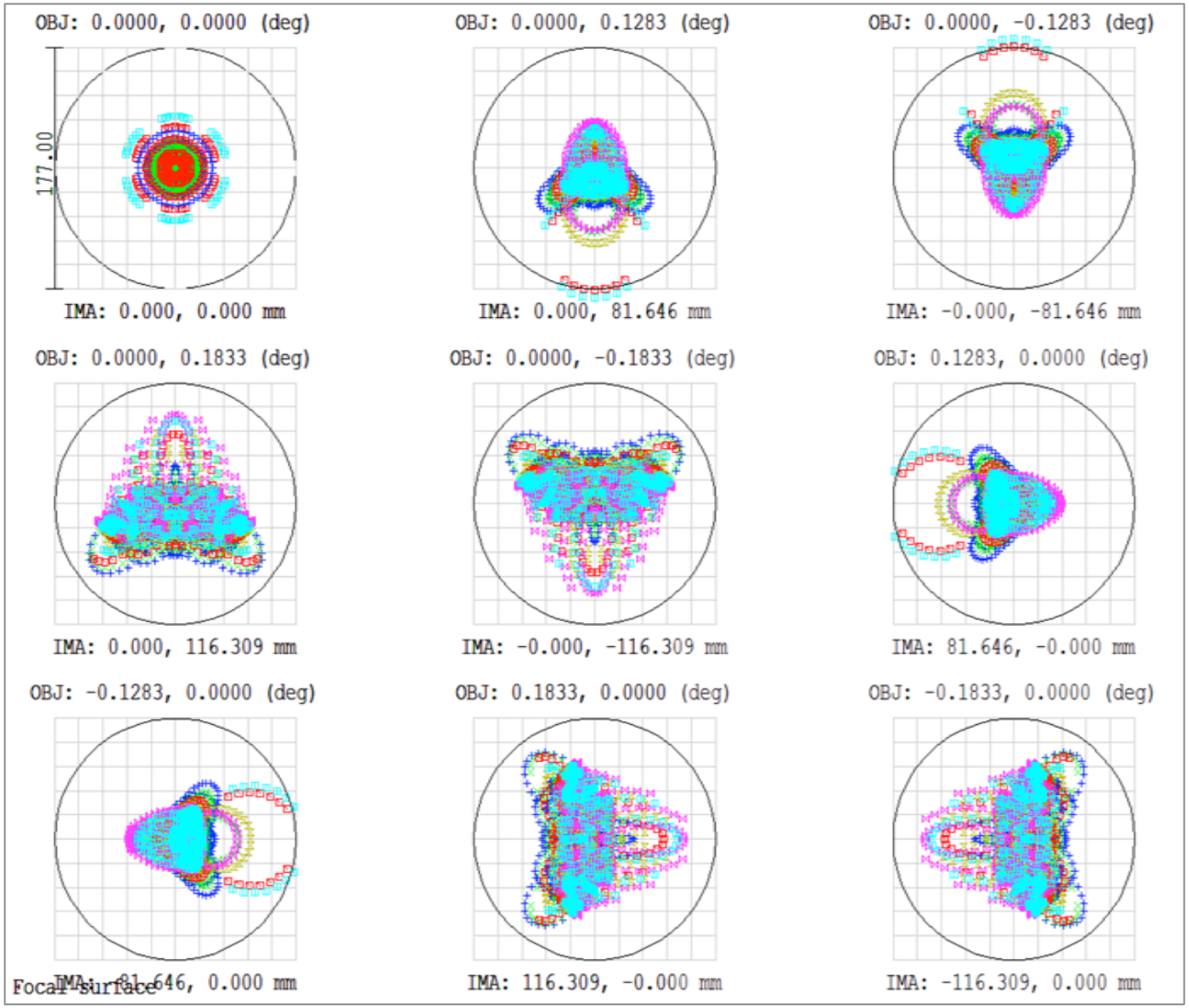
Circle diameter = 1 arcsecond



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Case #1
(Expected HET EE50 diameter)

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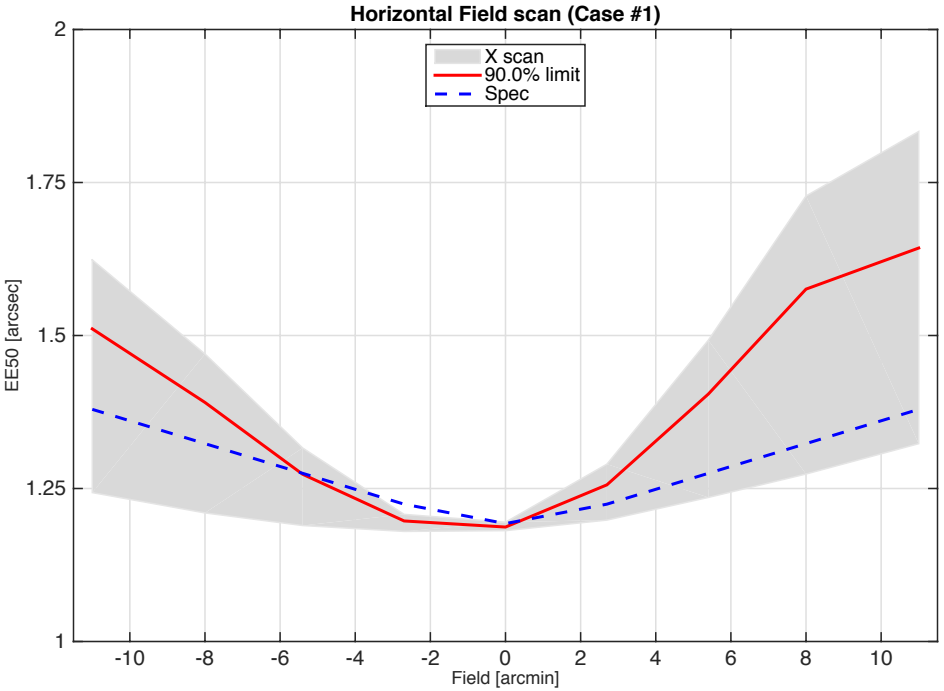
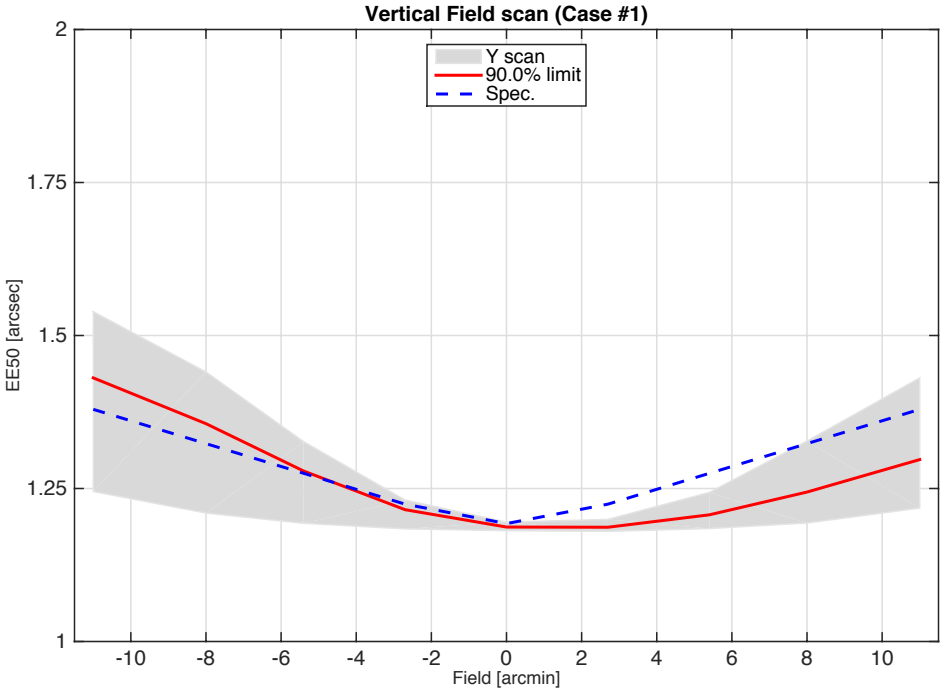
TYPE	M4/M5				Specification				Terms used					Weakest model included?
	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	COM	AST1 (90-deg)	AST2 (45-deg)	CRV	XY pos	
REL	**70.2** 56.0	**-19.8** 55.1	**-114.4** 88.0	**-156.6** 88.0	20	20	80	80	O	O	X	O	O	O
SYS	**-153** 56.0	**8.2** 55.1	**-37.8** 88.0	**49.2** 88.0	50	50	56.7	56.7						





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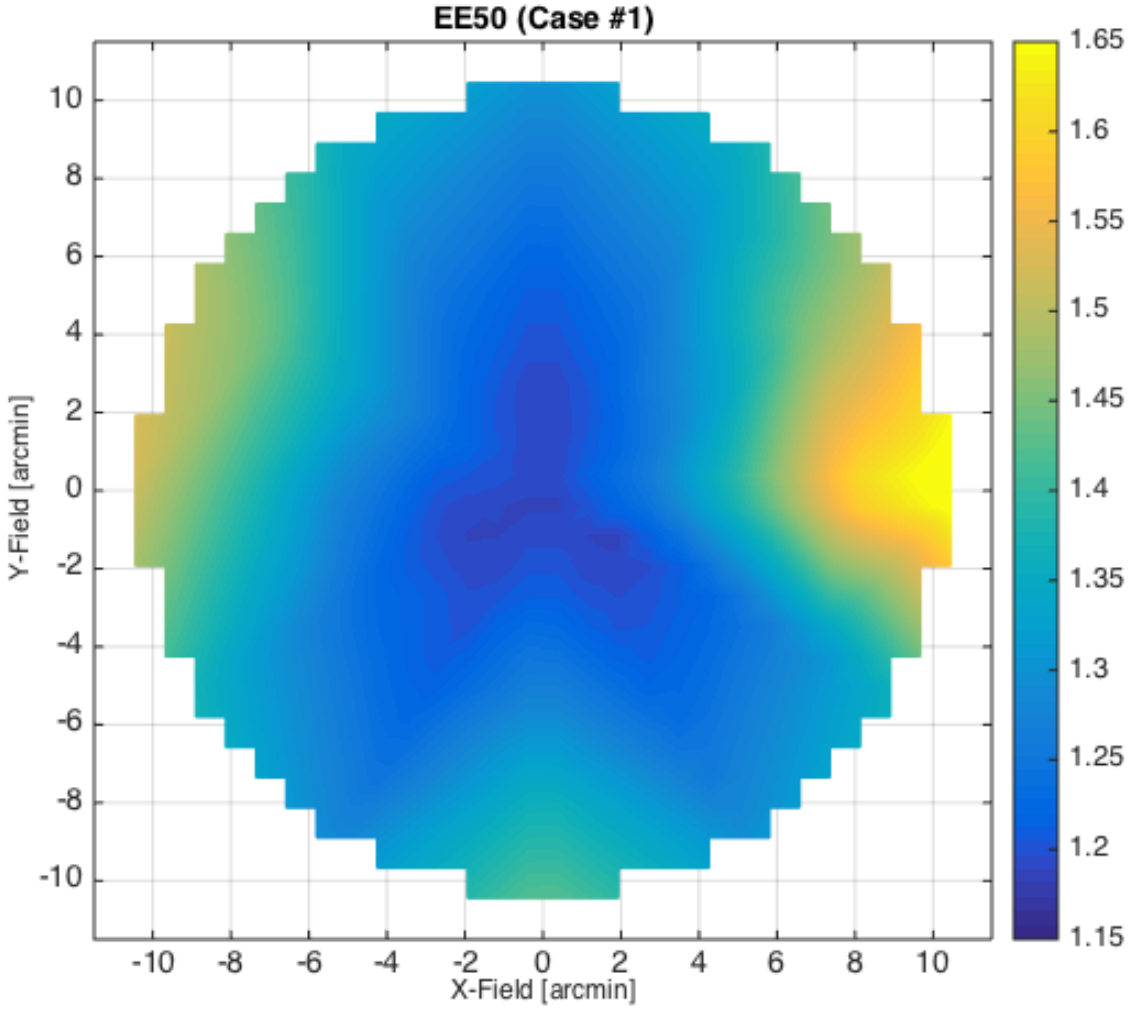
Case #1
(Expected HET EE50 diameter)



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Case #1- 496
(Spot diagram)

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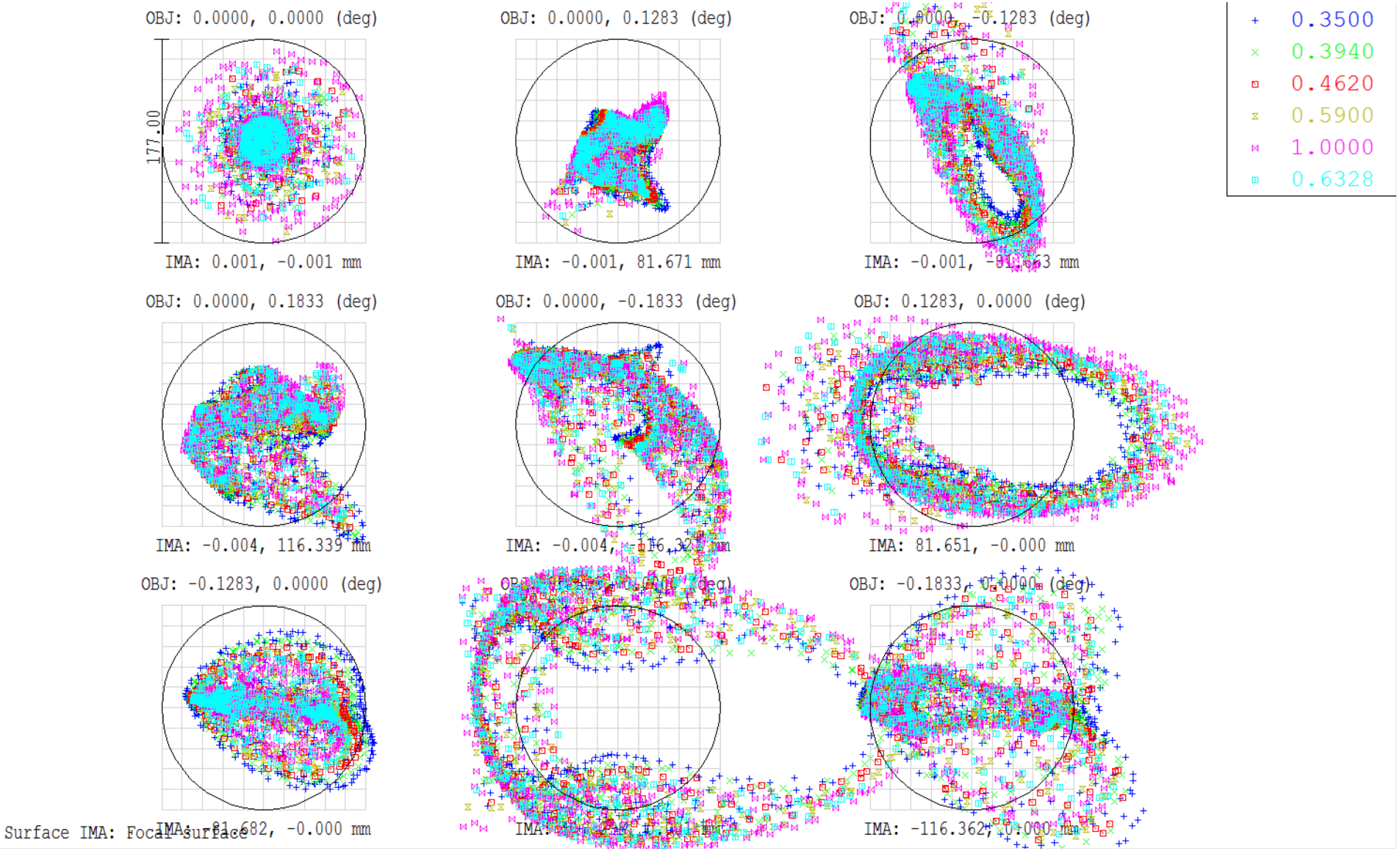

Surface IMA: Focal surface

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Case #2
(Expected HET EE50 diameter)

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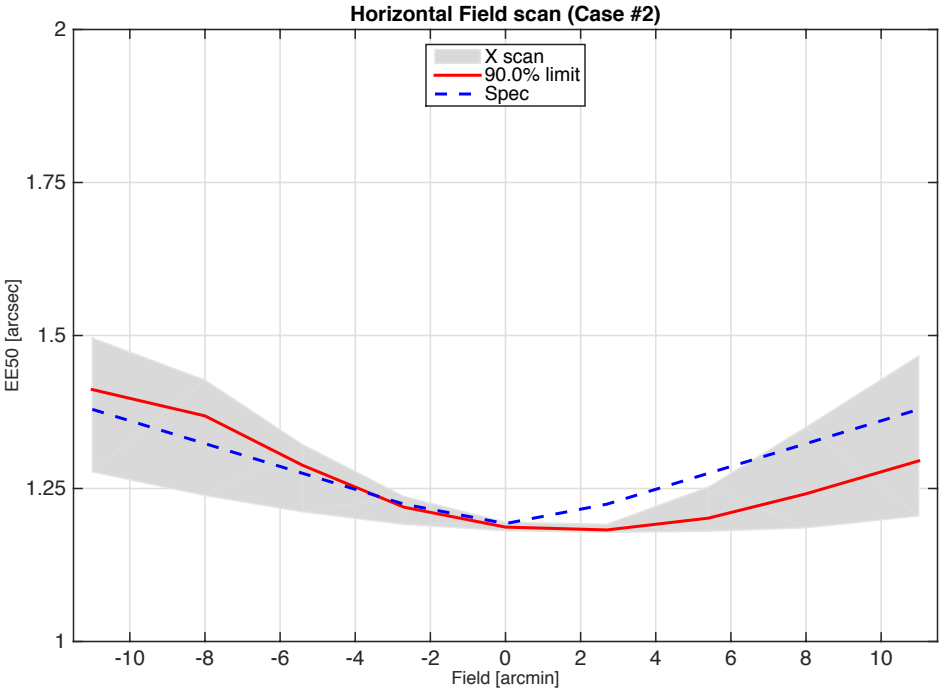
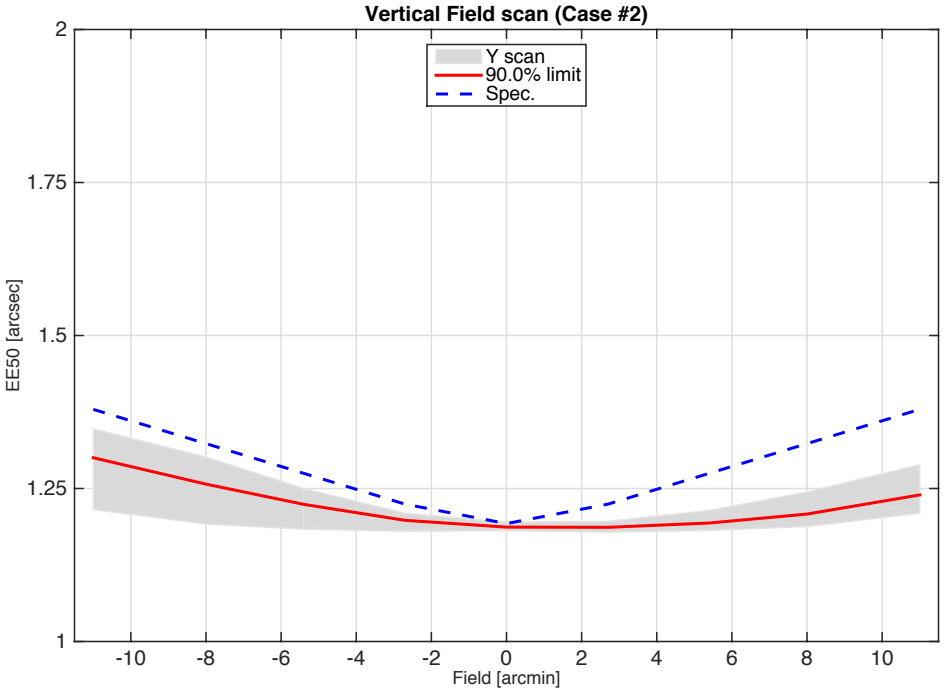
TYPE	M4/M5				Specification				Terms used					Weakest model included?
	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	COM	AST1 (90-deg)	AST2 (45-deg)	CRV	XY pos	
REL	**-35.7** 17.3	**-7.5** 17.0	**-31.8** 75.7	**189.2** 75.4	20	20	80	80	O	X	O	X	O	O
SYS	**4.45** 17.3	**1.15** 17.0	**13.3** 75.7	**80.3** 75.4	50	50	56.7	56.7						





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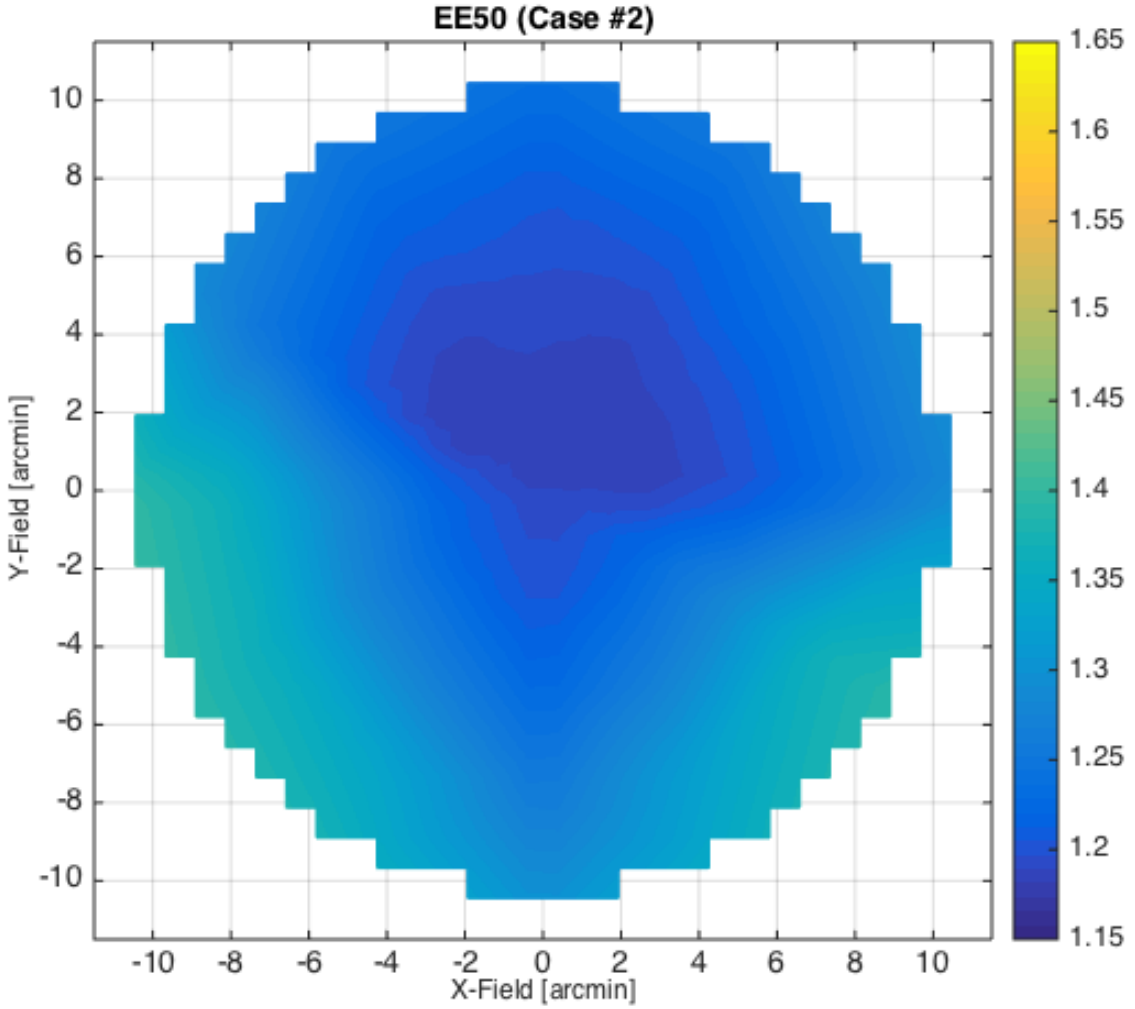
Case #2
(Expected HET EE50 diameter)



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Case #2 – 195
(Spot diagram)

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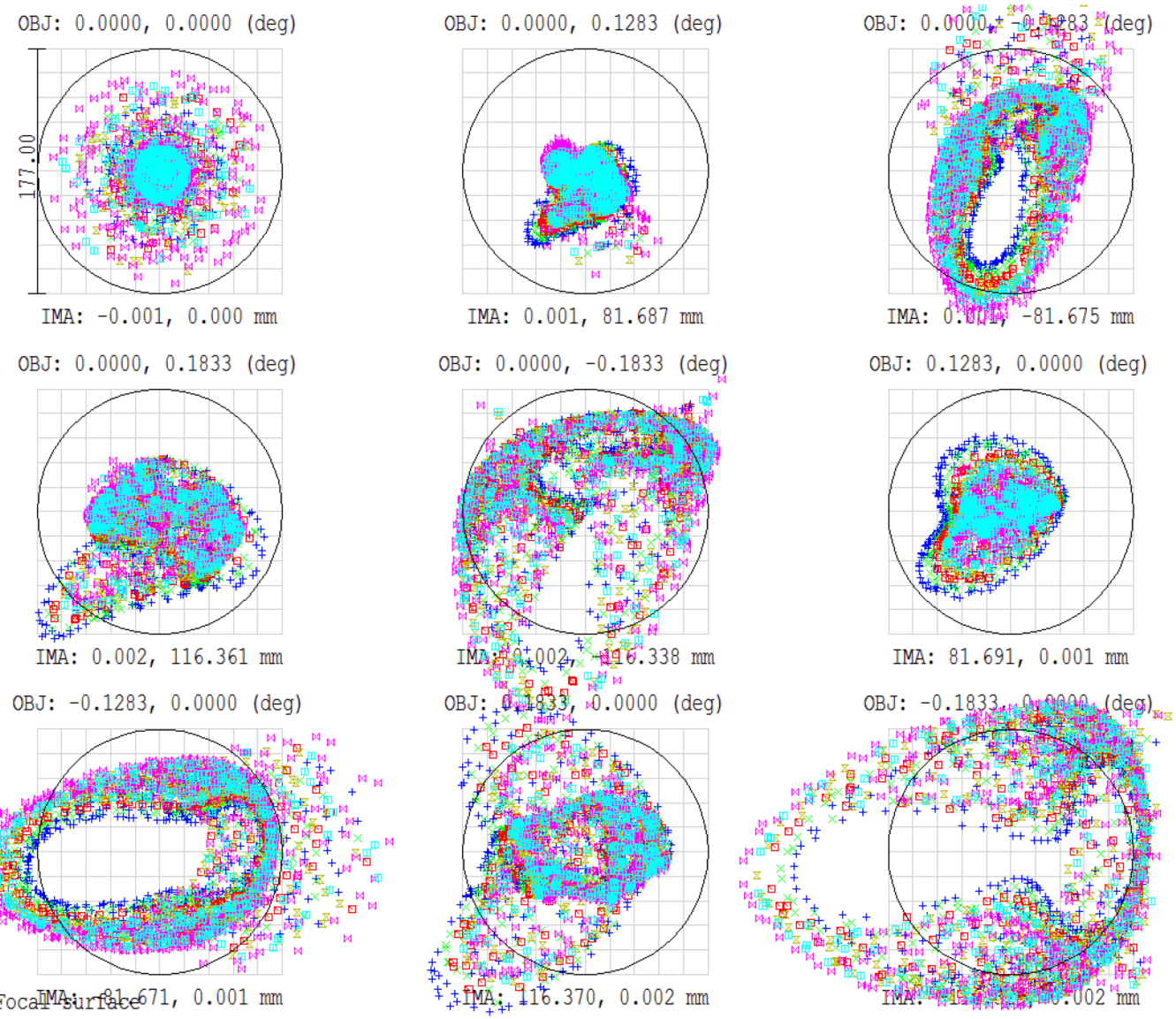

Surface IMA: Focal surface

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Case #3
(Expected HET EE50 diameter)

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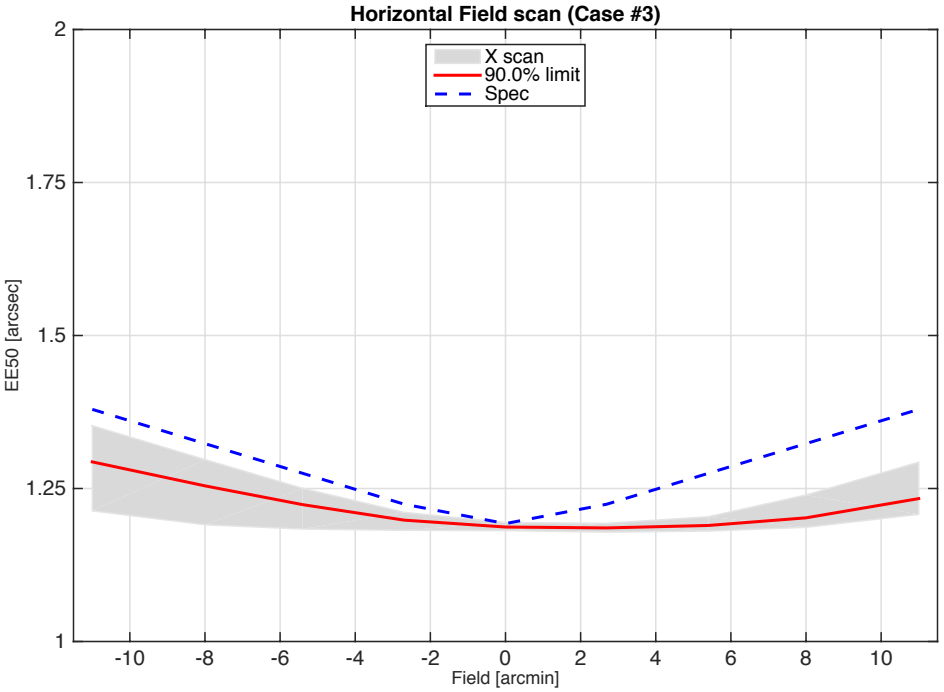
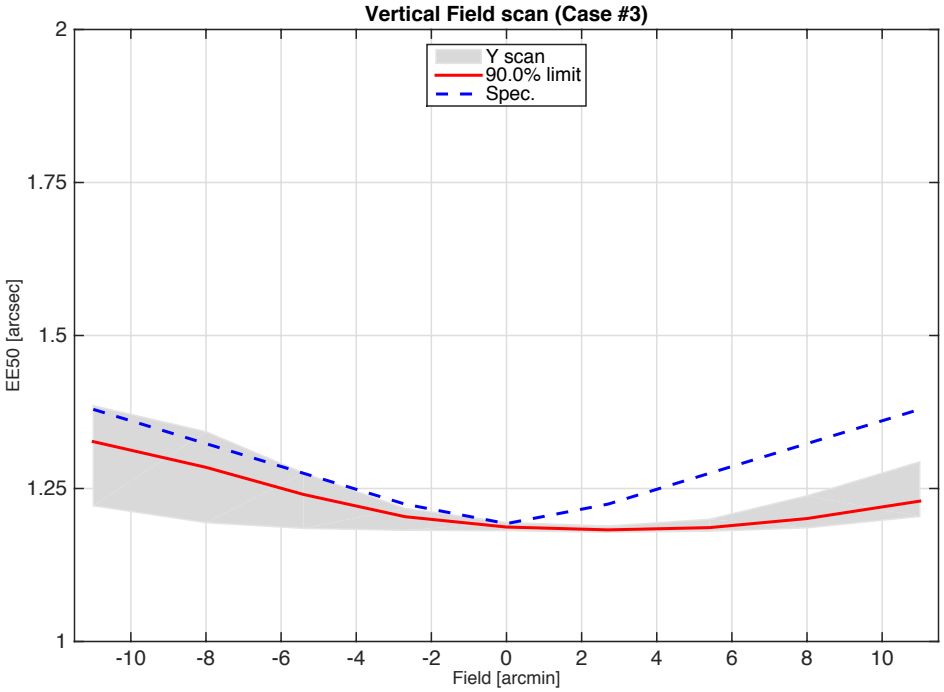
TYPE	M4/M5				Specification				Terms used					Weakest model included?
	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	COM	AST1 (90-deg)	AST2 (45-deg)	CRV	XY pos	
REL	**-13.3** 17.3	**-15.6** 17.0	**-107.4** 74.7	**-17.3** 74.8	20	20	80	80	O	O	X	O	O	X
SYS	**6.85** 17.3	**0.1** 17.0	**-44.2** 74.7	**-75.45** 74.8	50	50	56.7	56.7						





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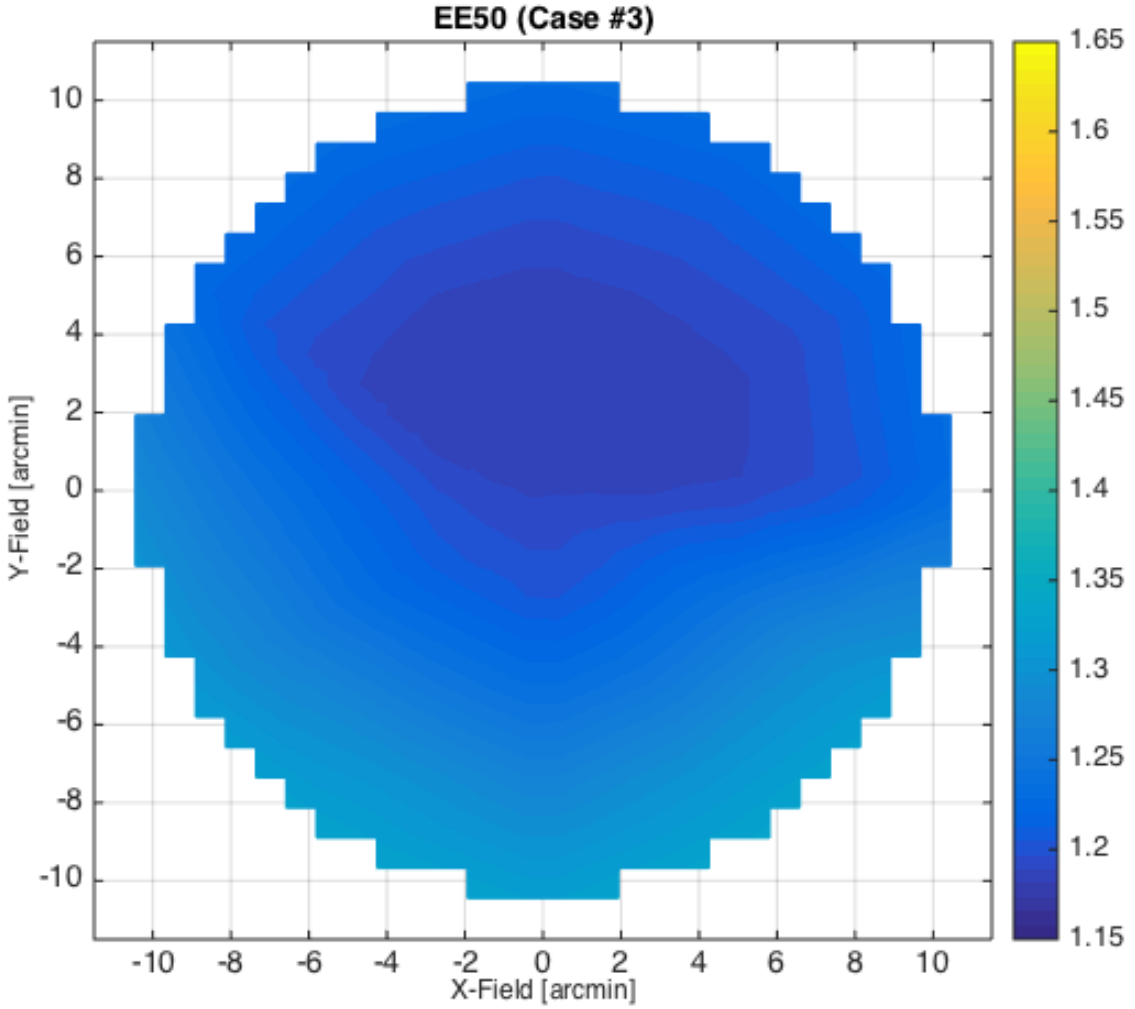
Case #3
(Expected HET EE50 diameter)



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Case #3 – 497
(Spot diagram)

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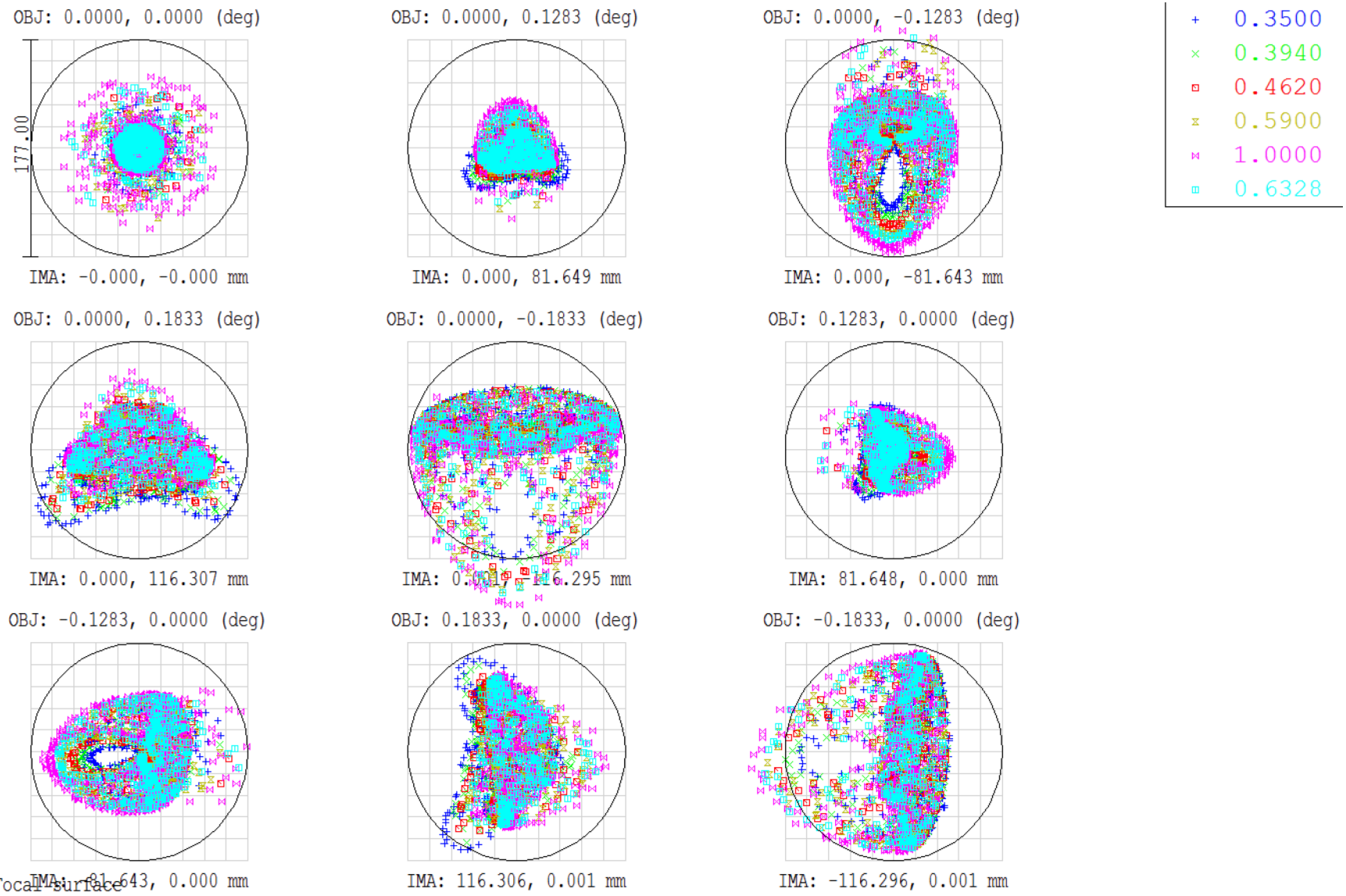

Surface IMA: Focal surface

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Case #4
(Expected HET EE50 diameter)

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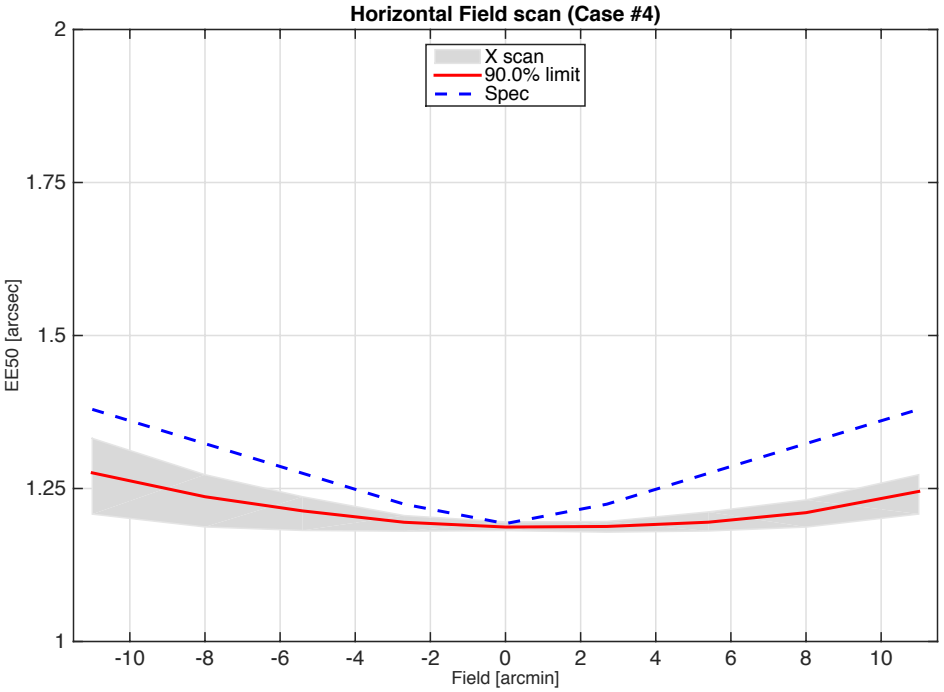
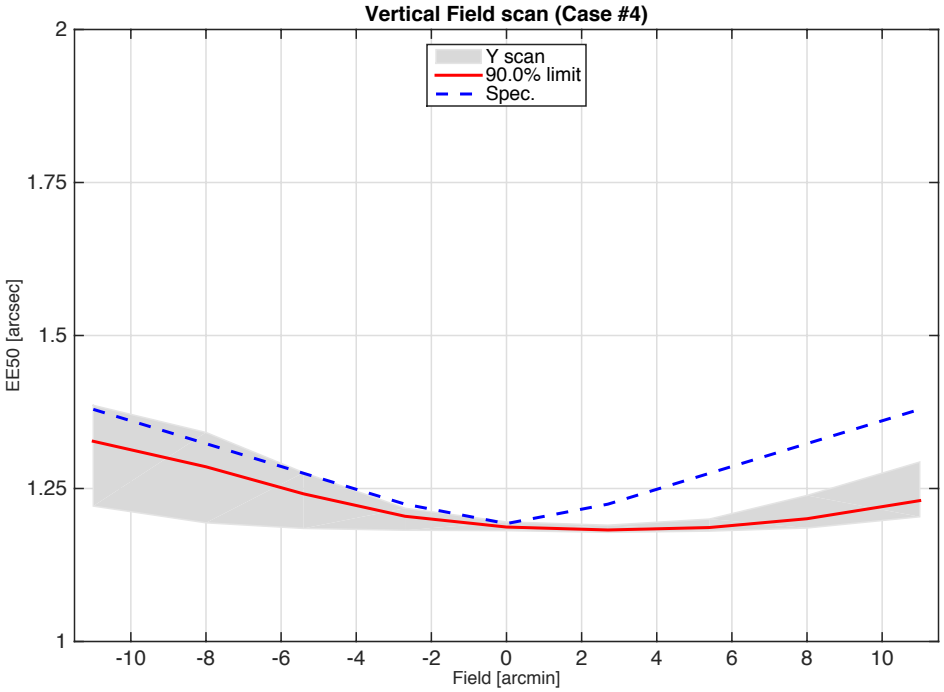
TYPE	M4/M5				Specification				Terms used					Weakest model included?
	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	COM	AST1 (90-deg)	AST2 (45-deg)	CRV	XY pos	
REL	**-8.8** 17.3	**-15.8** 17.0	**-109.5** 75.7	**-58.7** 75.5	20	20	80	80	O	O	X	X	O	O
SYS	**7.3** 17.3	**0.2** 17.0	**-45.65** 75.7	**-106.65** 75.5	50	50	56.7	56.7						





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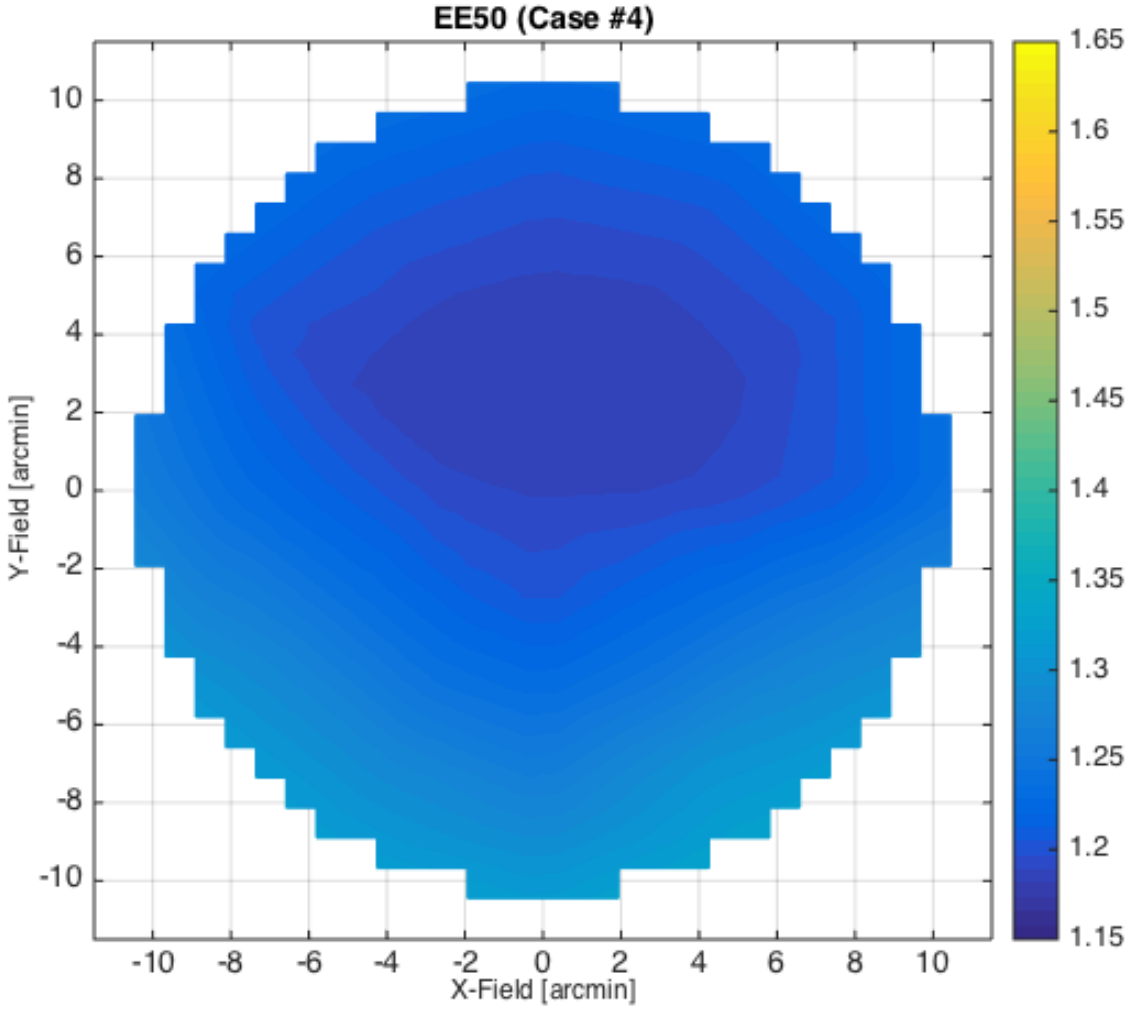
Case #4
(Expected HET EE50 diameter)



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Case #4 – 162
(Spot diagram)

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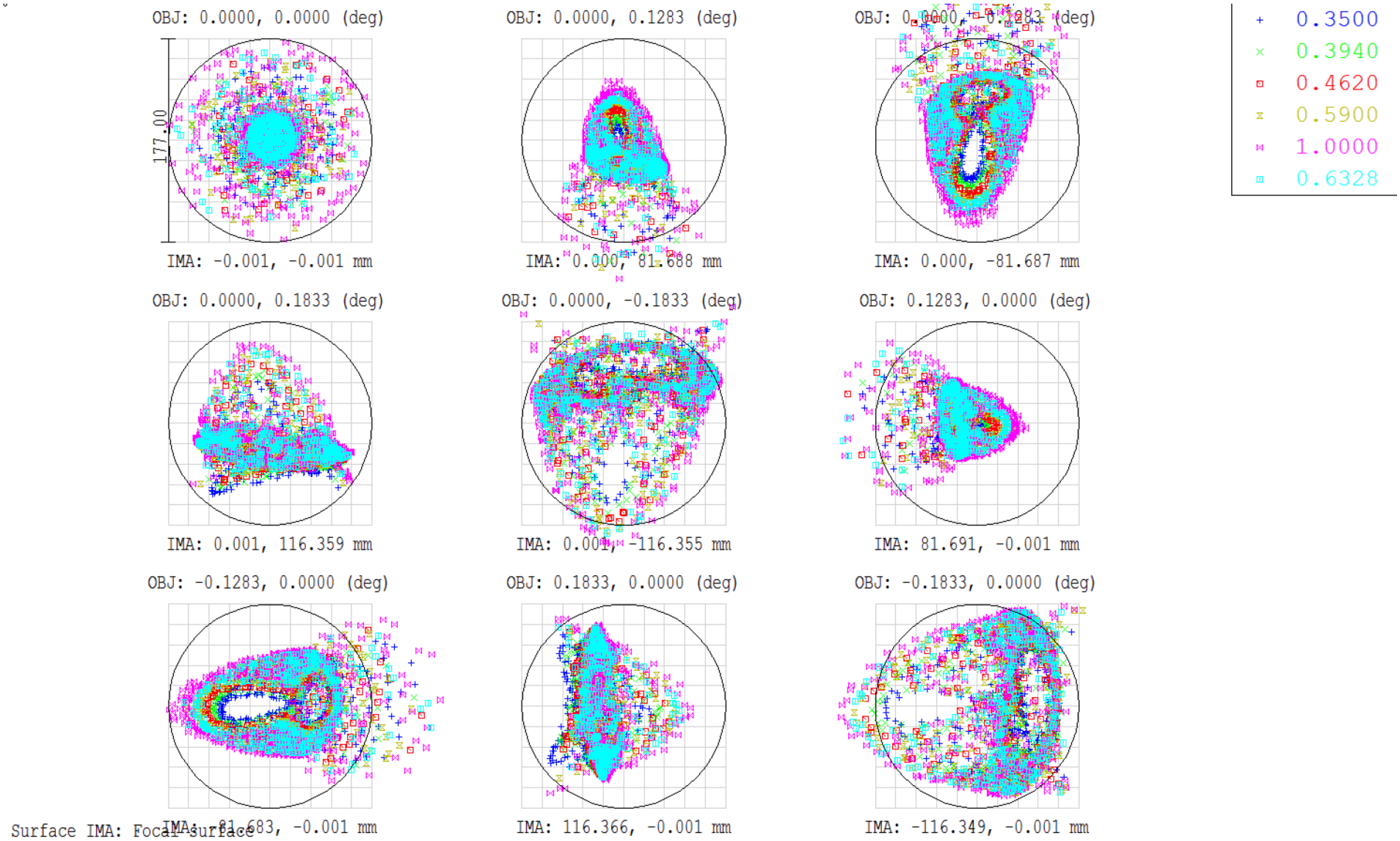

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Case #5
(Expected HET EE50 diameter)

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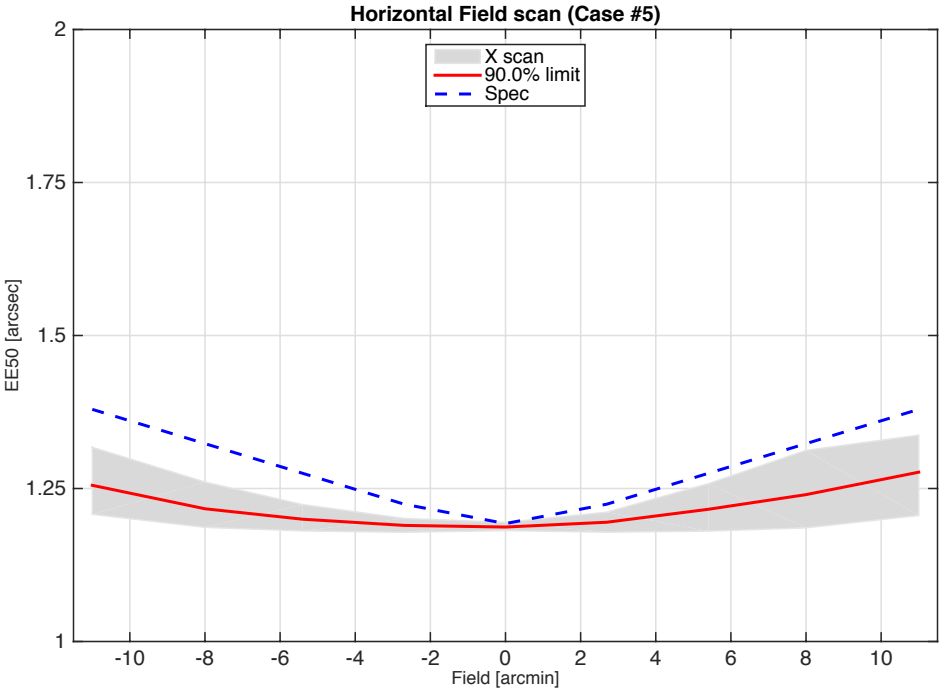
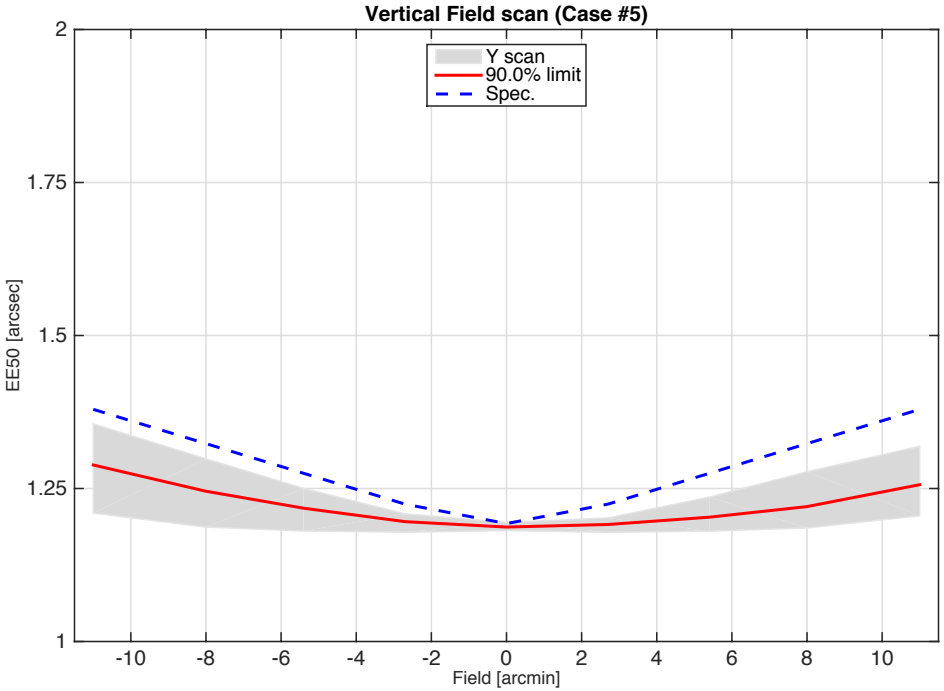
TYPE	M4/M5				Specification				Terms used					Weakest model included?
	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	COM	AST1 (90-deg)	AST2 (45-deg)	CRV	XY pos	
REL	**6.5** 53.3	**0.4** 52.2	**-55.7** 86.6	**29.6** 86.6	20	20	80	80	O	O	O	O	O	O
SYS	**-52.45** 53.3	**-23.4** 52.2	**-39.95** 86.6	**43.6** 86.6	50	50	56.7	56.7						





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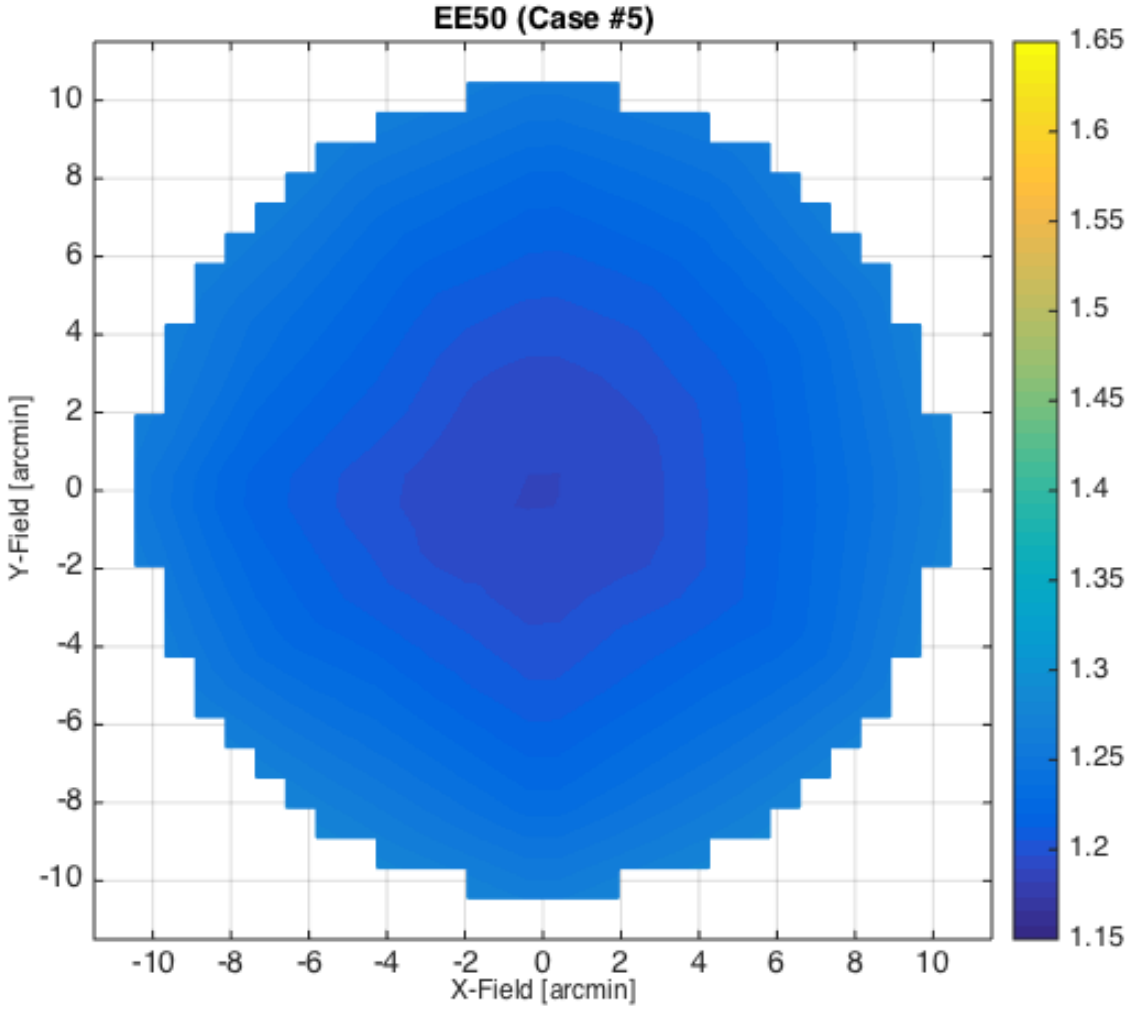
Case #5
(Expected HET EE50 diameter)



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Case #5 – 499
(Spot diagram)

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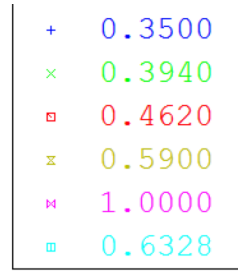

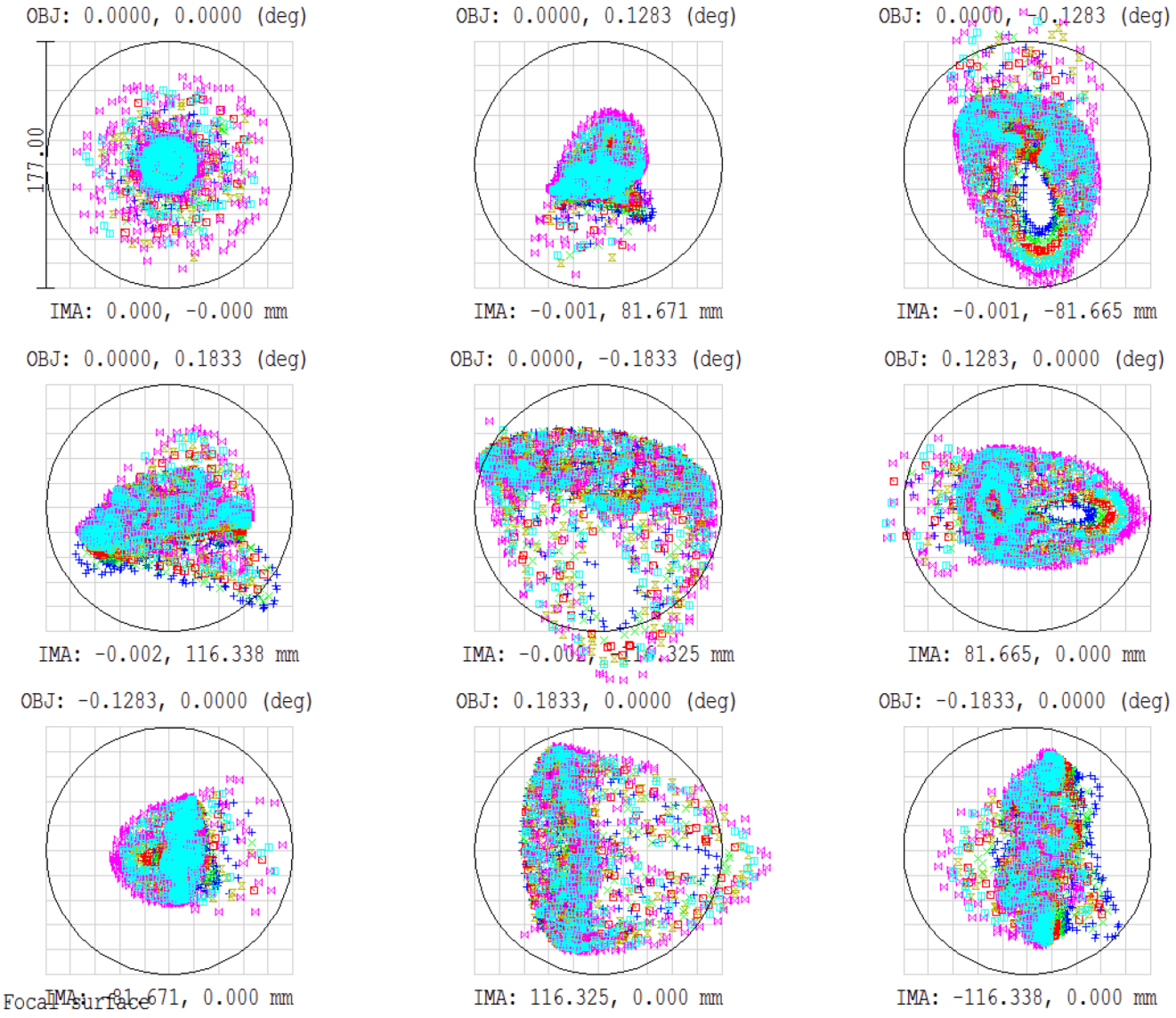

Surface IMA: Focal surface

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Case #6
(Expected HET EE50 diameter)

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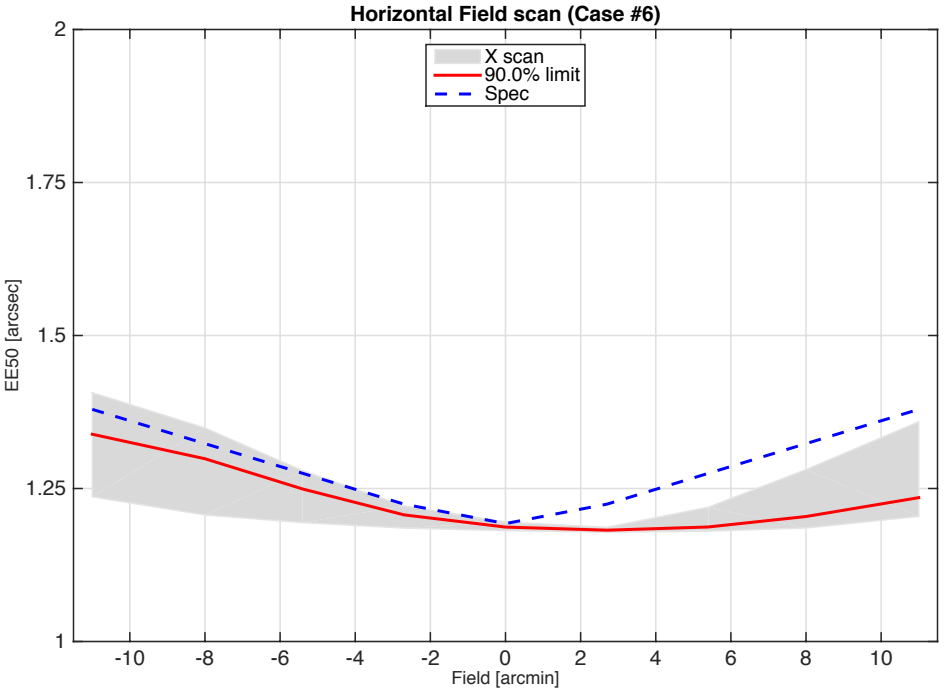
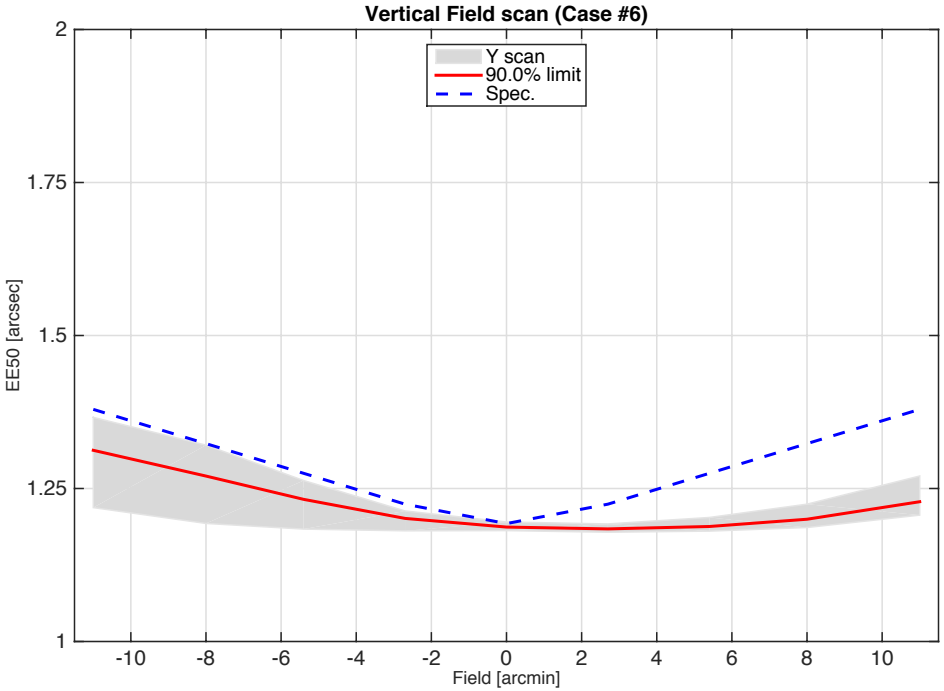
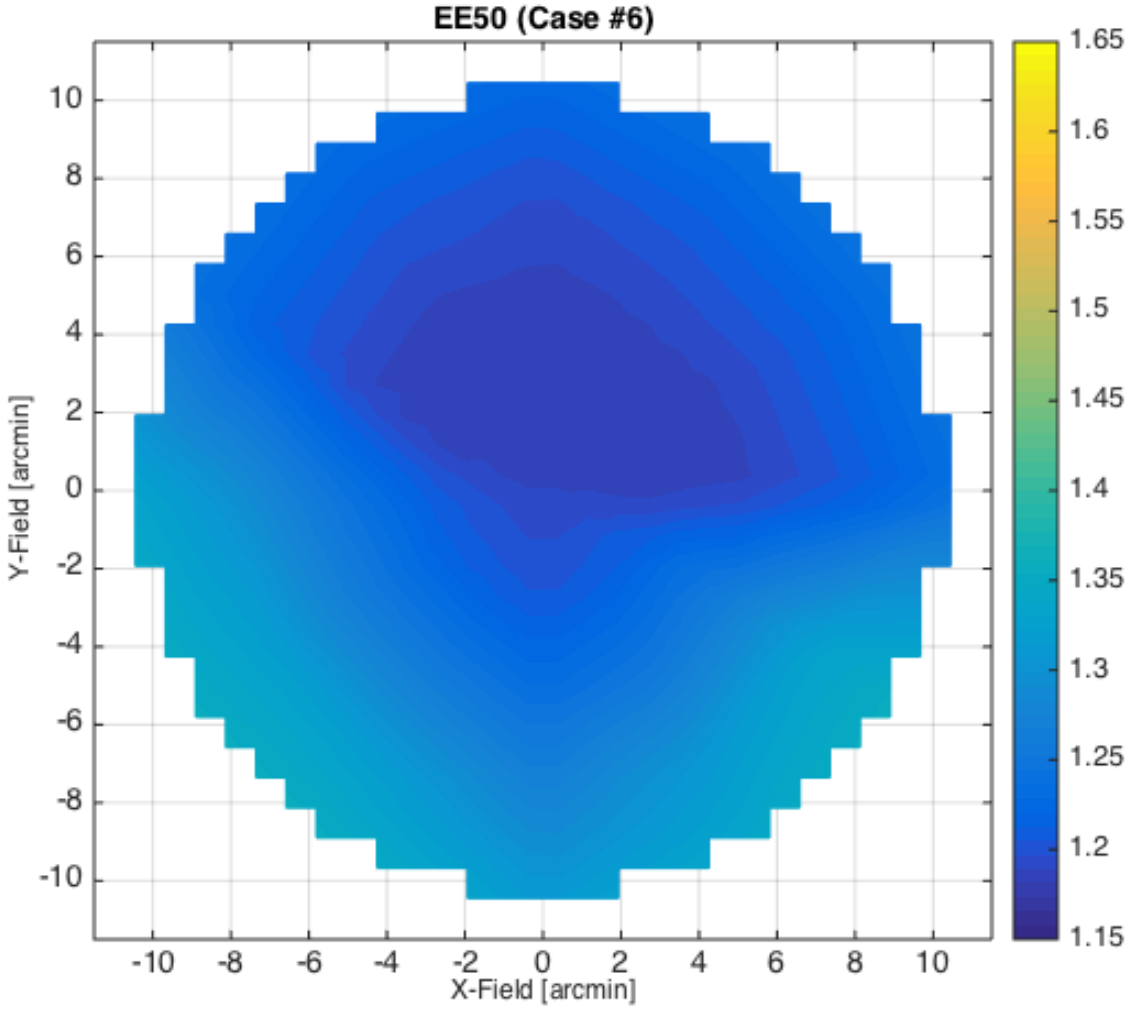
TYPE	M4/M5				Specification				Terms used					Weakest model included?
	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	DX (±2σ) [μm]	DY (±2σ) [μm]	Rx (±2σ) [μrad]	Ry (±2σ) [μrad]	COM	AST1 (90-deg)	AST2 (45-deg)	CRV	XY pos	
REL	**-23.2** 17.3	**-12** 17.0	**-74.1** 73.3	**73.6** 73.1	20	20	80	80	O	O	O	O	O	X
SYS	**5.7** 17.3	**0.6** 17.0	**-18.85** 73.3	**-6.7** 73.1	50	50	56.7	56.7						





Case #6
(Expected HET EE50 diameter)



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Case #6 – 5
(Spot diagram)

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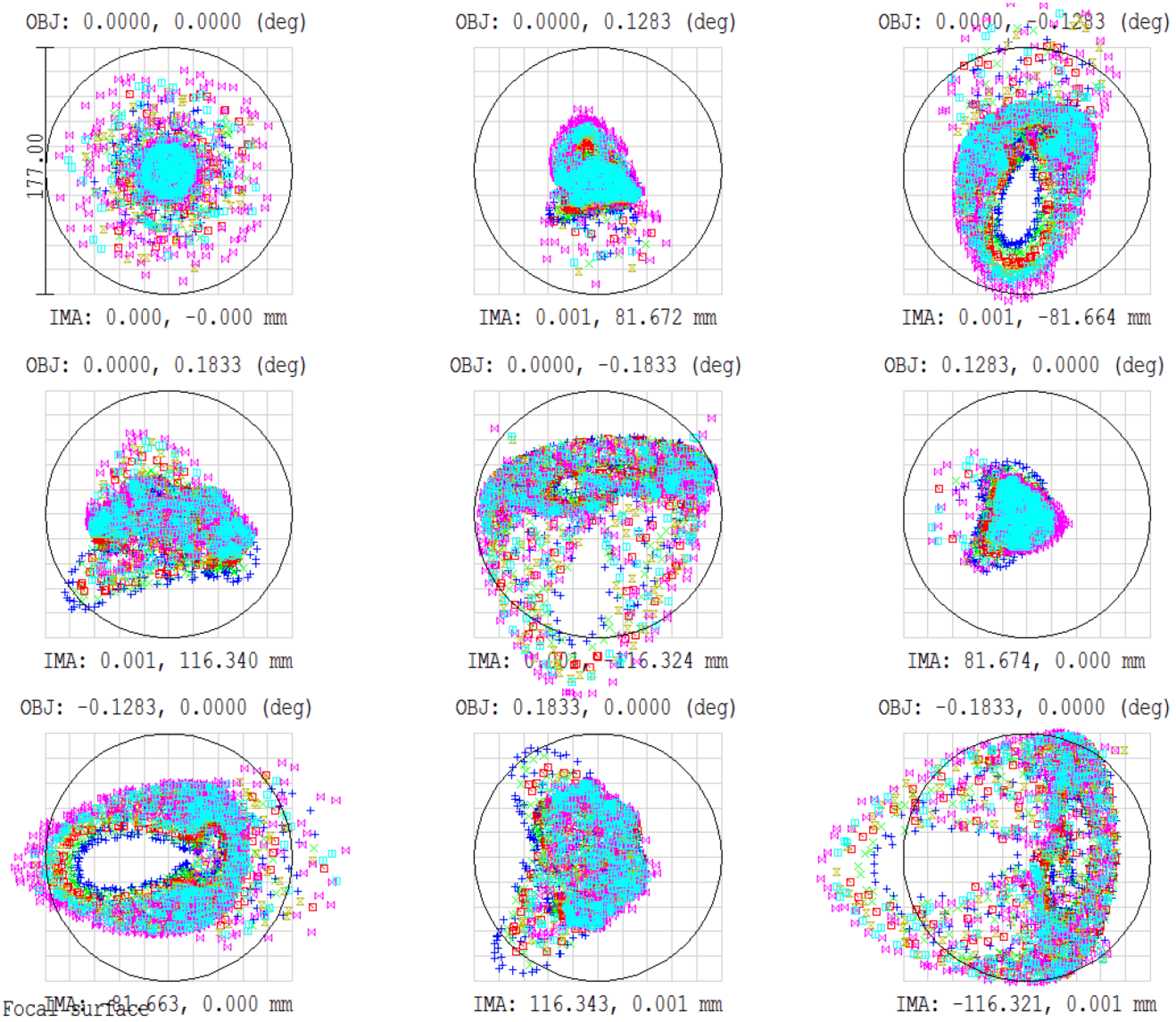

Surface IMA: Focal surface

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All cases

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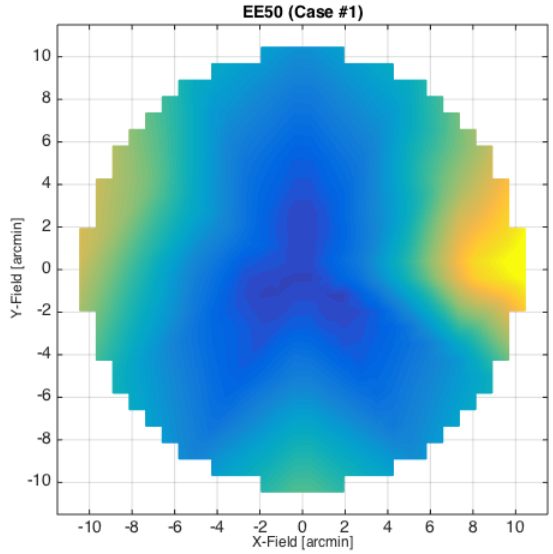

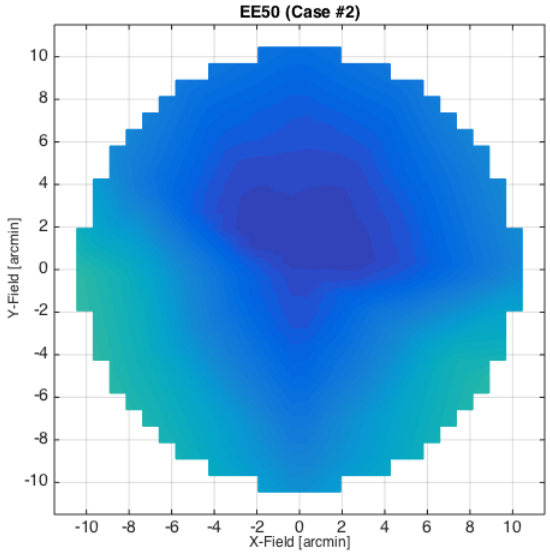

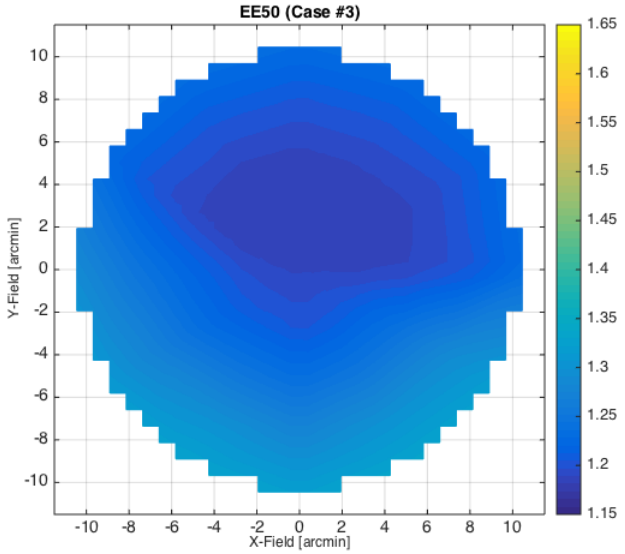

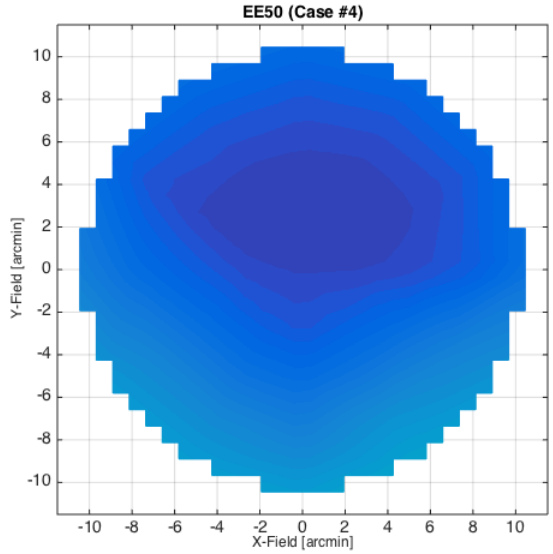

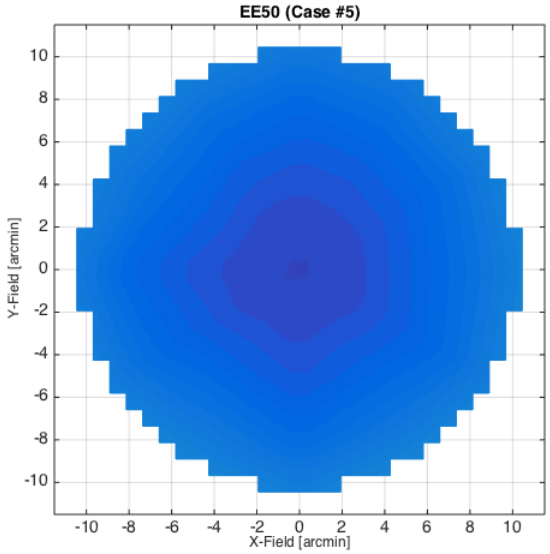

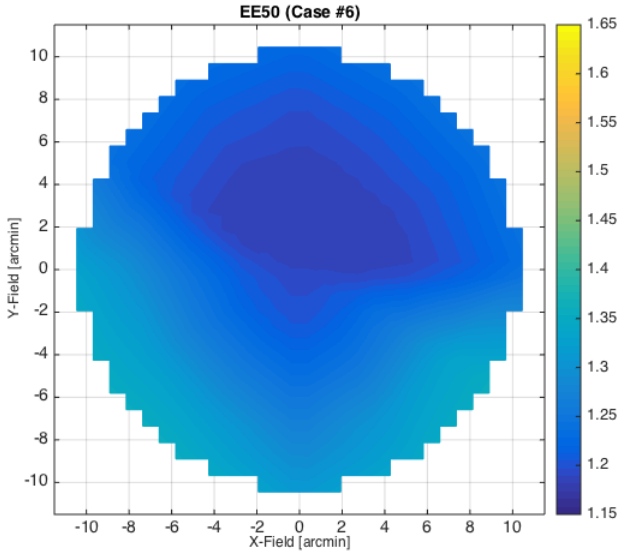

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Other requirements (for all cases)

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Metric	Requirement	Expectation	PASS/FAIL	Unit
Effective focal length	36450 – 36550	36492 – 36530	**PASS**	mm
Focal ratio*	3.645 – 3.655	3.649 – 3.653	**PASS**	--
Max. marginal ray angle	7.863 – 7.884	7.780 – 7.791	**ACCEPTABLE**	degrees
Max. telecentric angle	0.0 – 0.01	0.0032 – 0.0048	**PASS**	degrees
Max. distortion	0.0 – 1	< 0.585	**PASS**	%
Un-vignetted portion of beam	> 80 on-axis > 64 at edge	> 80 on-axis > 64 at edge	**PASS**	%

* Focal ratio is the paraxial focal ratio given by EFL / 10m pupil at on-axis.

Summary

- **5 out of 6 possibilities are within the specification.**
  - Laser tracker / Center reference data favor other cases againt Case 1.
  - Case 1 would require substantial amount of focal surface tilt to compensate the image quality.
    - However, this would result in the WFC system that severely violates the telecentric angle requirements.
    - Astigmatism remains unchanged after FPA tilt, resulting in elongated / asymmetric PSF shape → Guiding issue (to be addressed in the next presentation).

- **Other requirements appear to meet the specifications.**
  - These requirements are fundamentally dependent on the WFC system prescriptions (mirror prescriptions + axial positions).
  - Lateral misalignment (decenter / tilt) has negligible influence on these parameters.

- **On-sky image quality verification & compensation plan is presented in the next.**