Wavefront Aberrations due to Alignment and Figure Compensation of the NASA James Webb Space Telescope
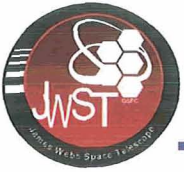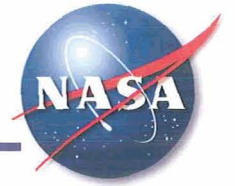
Joe Howard

JWST OTE Lead Optical Designer

NASA – Goddard Space Flight Center

2007 SPIE Optics and Photonics, San Diego, August 30

NORTHROP GRUMMAN
Space Technology
Ball
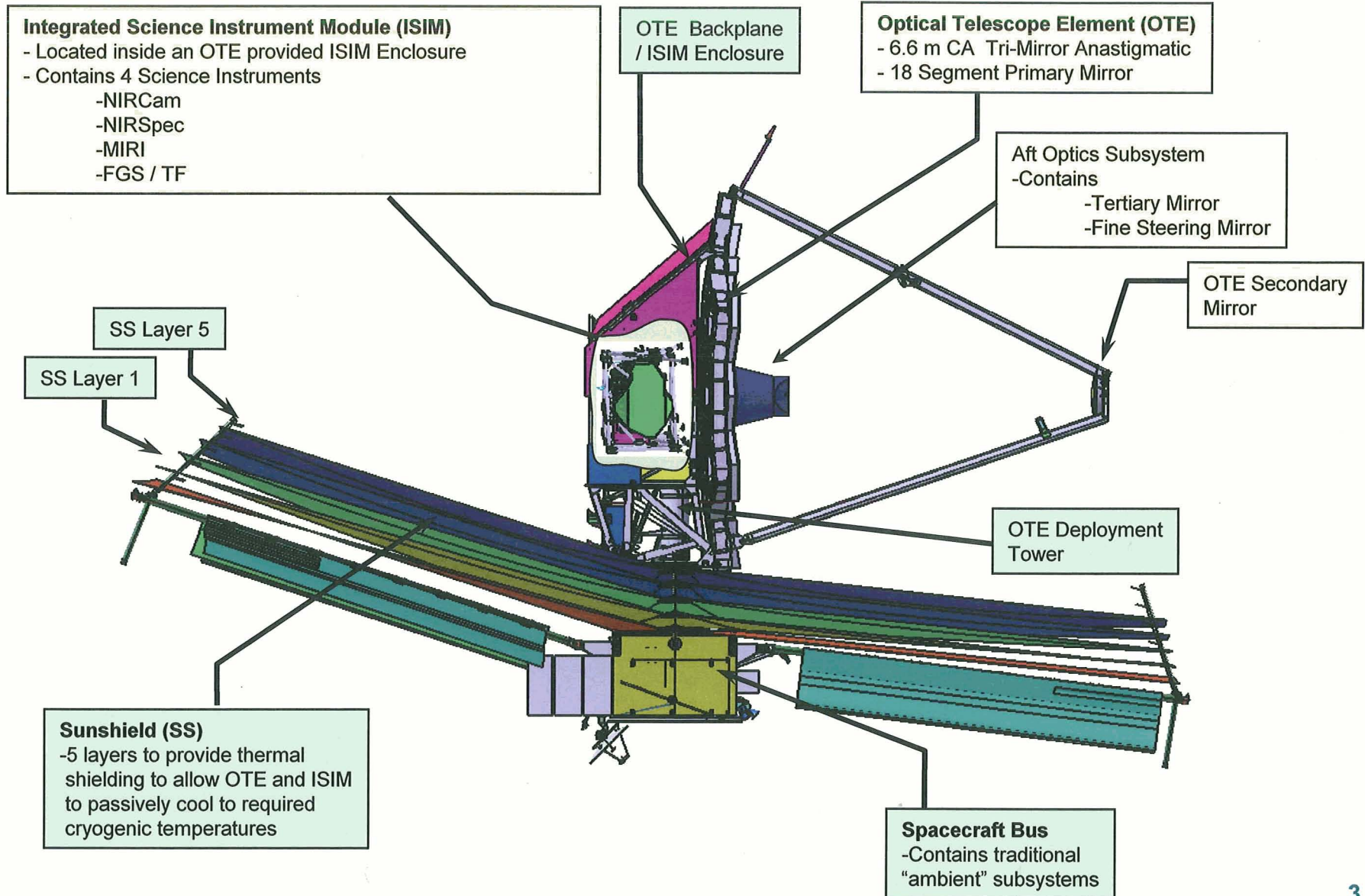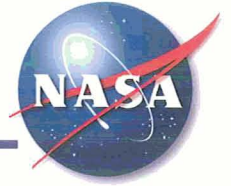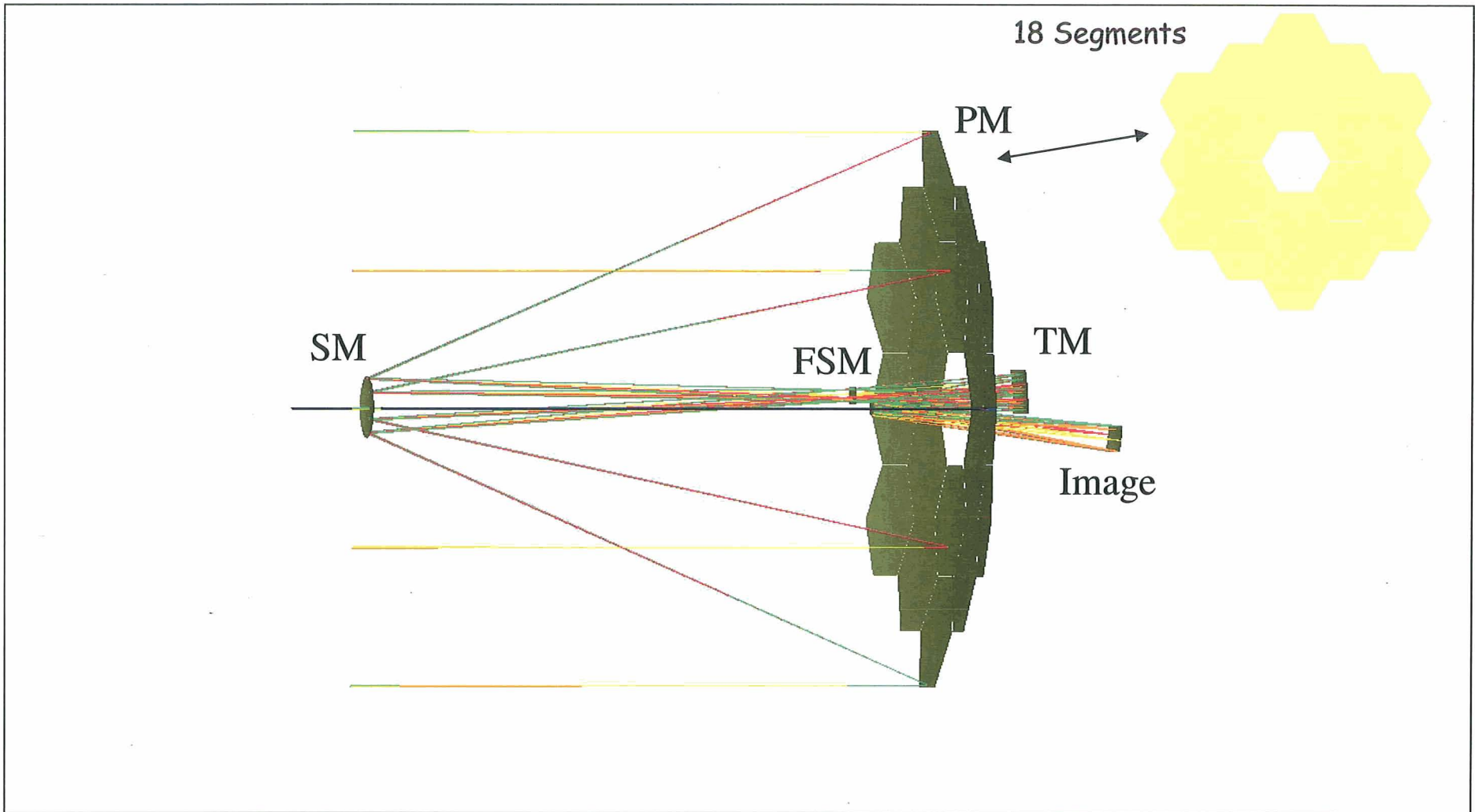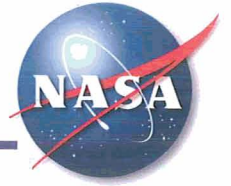ITT Industries *Engineered for life*
ATK

Outline

1. Introduction to JWST

2. Observable alignment modes

3. Compensator modes

4. Field impact from improper compensation

5. Concluding remarks

Integrated Science Instrument Module (ISIM)
- Located inside an OTE provided ISIM Enclosure
- Contains 4 Science Instruments
  - NIRCam
  - NIRSpec
  - MIRI
  - FGS / TF

OTE Backplane / ISIM Enclosure

Optical Telescope Element (OTE)
- 6.6 m CA Tri-Mirror Anastigmatic
- 18 Segment Primary Mirror

Aft Optics Subsystem
-Contains
    -Tertiary Mirror
    -Fine Steering Mirror

OTE Secondary Mirror

SS Layer 5

SS Layer 1

OTE Deployment Tower

Sunshield (SS)
-5 layers to provide thermal shielding to allow OTE and ISIM to passively cool to required cryogenic temperatures

Spacecraft Bus
-Contains traditional "ambient" subsystems

3

Three-Mirror-Anastigmat (TMA) wide-field telescope design

	X	Y	Z	rot X	rot Y	rot Z
PM						
SM						
TM						
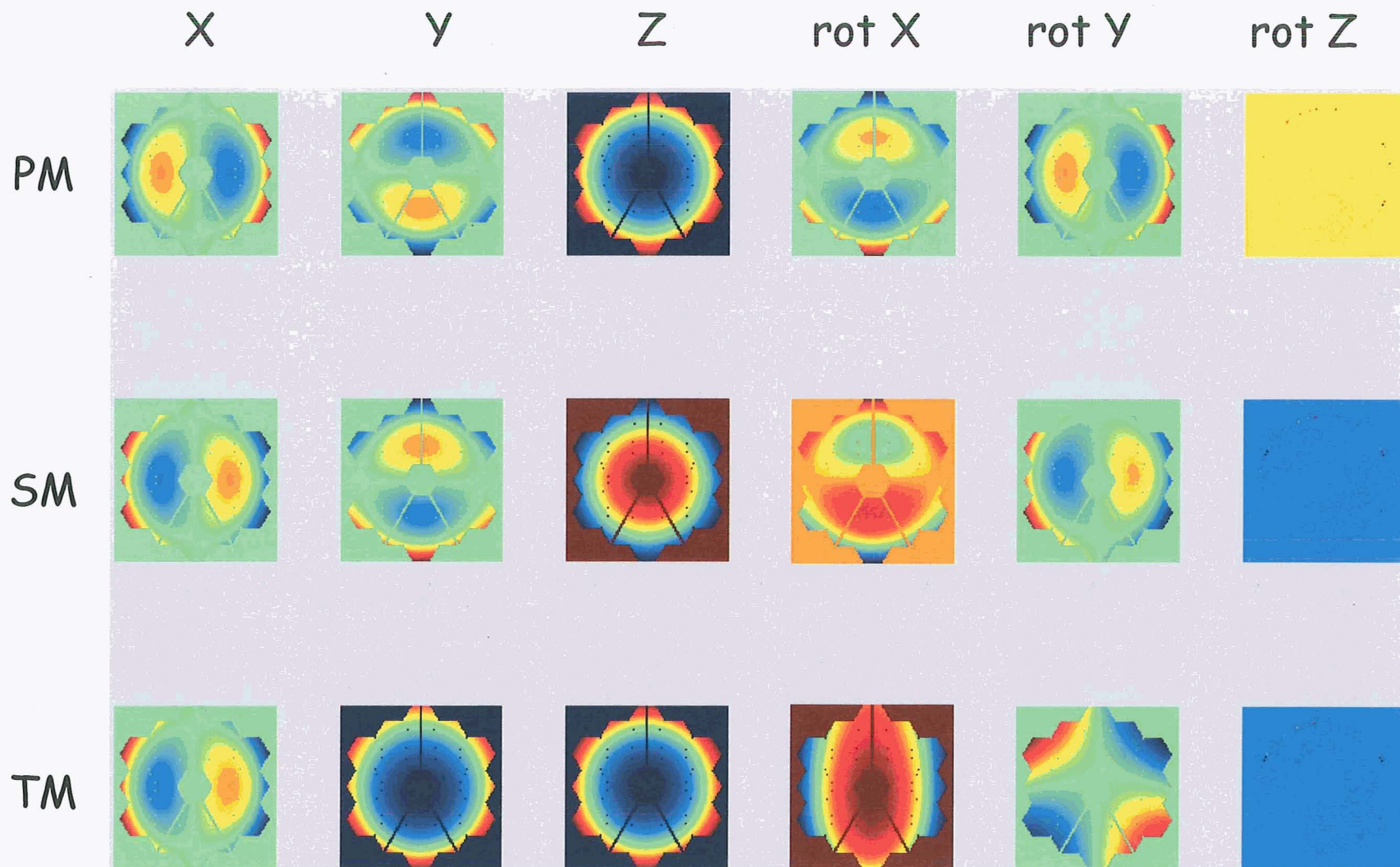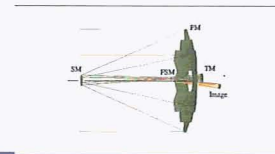
Low order Zernike Polynomials
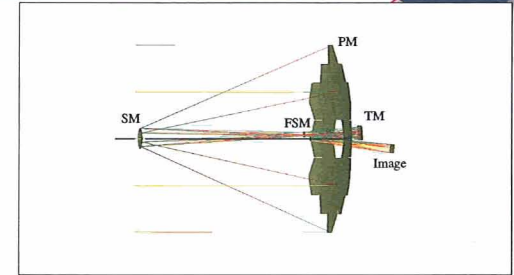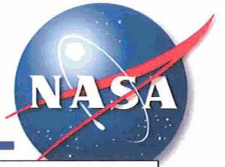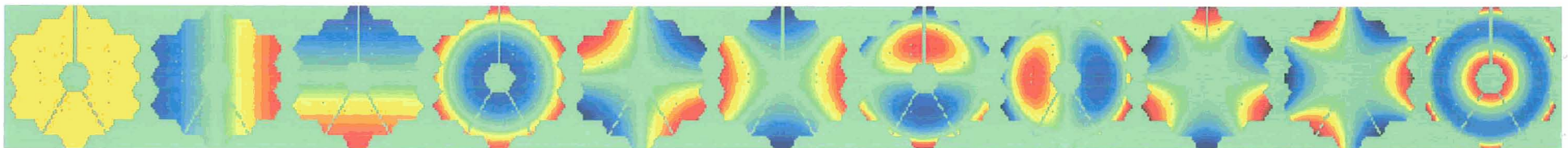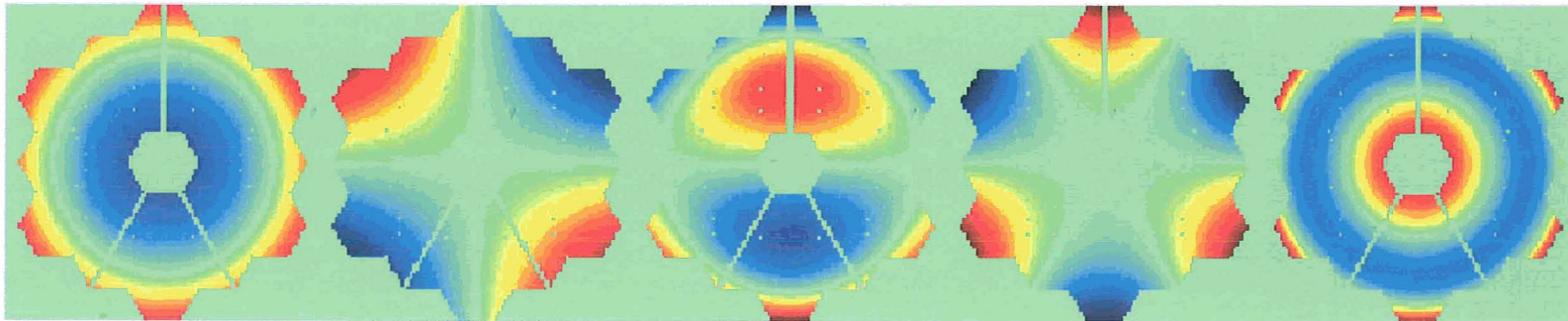
PM SM Ability to Target Low Order Aberrations

ASSUMPTION: All "Target" Aberrations at 100 nm RMS WFE
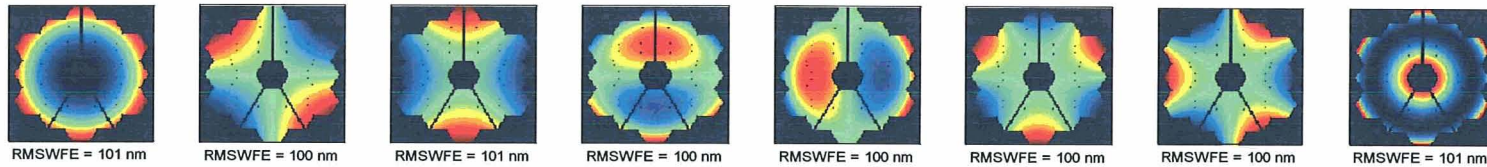
	A1	A2	A3	A4	A5	A6	A7	A8
	RMSWFE = 101 nm	RMSWFE = 100 nm	RMSWFE = 101 nm	RMSWFE = 100 nm	RMSWFE = 100 nm	RMSWFE = 100 nm	RMSWFE = 100 nm	RMSWFE = 101 nm
	Power	Astig 45	Astig	Coma	Coma 90	Trefoil	Trefoil 60	Spherical
PM align	100	100	98	93	92	3	2	24
PM figure	100	100	100	93	92	100	100	100
SM align	100	100	100	93	92	3	3	24
SM figure	100	100	100	100	100	100	100	100
PM SM align	n/a	n/a	n/a	n/a	n/a	n/a	n/a	100

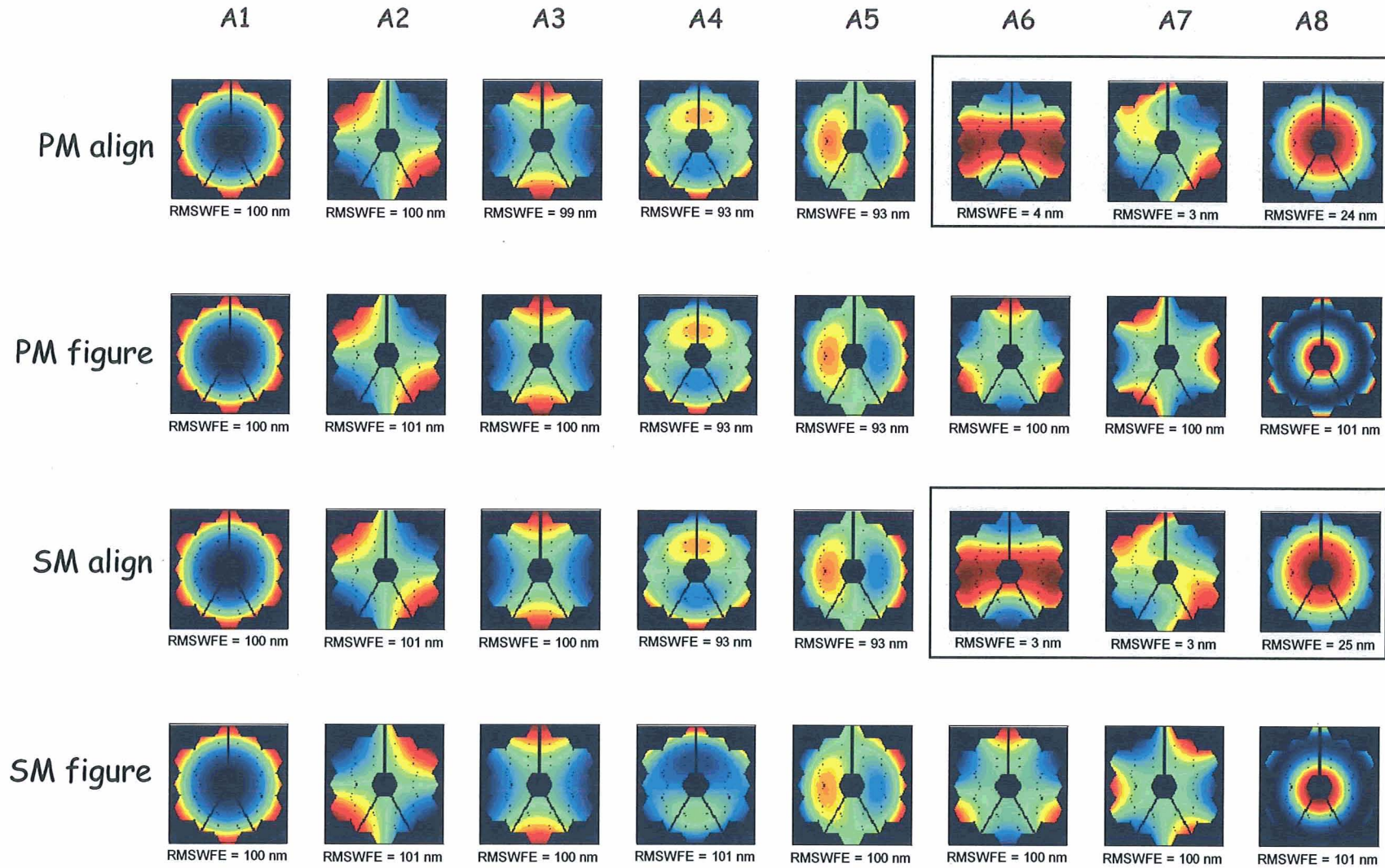|	A1	A2	A3	A4	A5	A6	A7	A8
PM align	RMSWFE = 100 nm	RMSWFE = 100 nm	RMSWFE = 99 nm	RMSWFE = 93 nm	RMSWFE = 93 nm	RMSWFE = 4 nm	RMSWFE = 3 nm	RMSWFE = 24 nm
PM figure	RMSWFE = 100 nm	RMSWFE = 101 nm	RMSWFE = 100 nm	RMSWFE = 93 nm	RMSWFE = 93 nm	RMSWFE = 100 nm	RMSWFE = 100 nm	RMSWFE = 101 nm
SM align	RMSWFE = 100 nm	RMSWFE = 101 nm	RMSWFE = 100 nm	RMSWFE = 93 nm	RMSWFE = 93 nm	RMSWFE = 3 nm	RMSWFE = 3 nm	RMSWFE = 25 nm
SM figure	RMSWFE = 100 nm	RMSWFE = 101 nm	RMSWFE = 100 nm	RMSWFE = 101 nm	RMSWFE = 100 nm	RMSWFE = 100 nm	RMSWFE = 100 nm	RMSWFE = 101 nm

Figure of Merit: 100 nm is good, less shows inability of alignment/figure mode to match aberration.

Compensator Definitions and Modes

Error sources

       PM Alignment — i.e. 6 DOF alignment

       SM Alignment, 6 DOF motion

       SM Figure — low order Zernike Aberrations

Compensators to be used

       PM Figure — i.e. non-common segment motion

       PM Alignment — i.e. 6 DOF alignment

       SM Alignment, 6 DOF motion

Example: SM Alignment compensated with PM Figure

Nominal (5nm)   SM Alignment Error (100 nm)   PM Figure Compensation (1 nm)

RMSWFE = 5 nm   RMSWFE = 101 nm   RMSWFE = 1 nm

(Nominal is backed out)

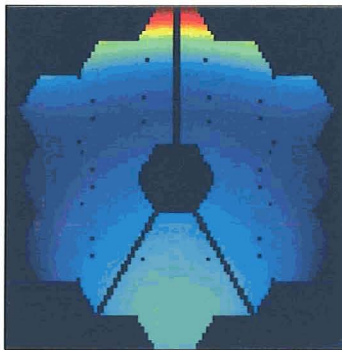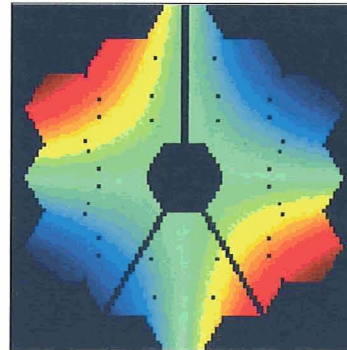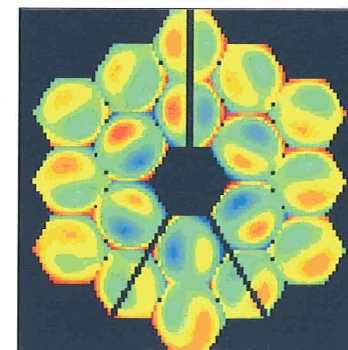# Field impact from compensation

Initial Error = 100 nm

FULL FOV WORST CASE FIELD POINT in RMS WFE (nm)

	ERROR	COMP	Power	Astig 45	Astig	Coma	Coma 90	Trefoil	Trefoil 60	Spherical
c1	PM ali	PM fig	5	114	136	5	5	8	6	4
c2	PM ali	SM ali	3	119	73	6	6	5	4	3
c3	SM ali	PM ali	2	119	60	5	7	4	5	1
c4	SM ali	PM fig	5	166	119	7	8	8	7	3
c5	SM fig	PM ali	0	113	102	14	26	104	110	59
c6	SM fig	PM fig	0	1	1	23	33	19	26	24
c7	SM fig	SM ali	0	165	119	1	1	104	114	59
c8	SM fig	PM SM ali	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5

FULL FOV WORST CASE FIELD POINT at BEST FOCUS in RMS WFE (nm)

	ERROR	COMP	Power	Astig 45	Astig	Coma	Coma 90	Trefoil	Trefoil 60	Spherical
c1	PM ali	PM fig	5	114	136	5	5	8	6	4
c2	PM ali	SM ali	0	14	12	1	1	1	1	0
c3	SM ali	PM ali	0	16	11	0	0	1	0	0
c4	SM ali	PM fig	4	116	99	4	5	8	5	3
c5	SM fig	PM ali	0	113	102	2	1	104	110	59
c6	SM fig	PM fig	0	1	1	17	20	19	26	23
c7	SM fig	SM ali	0	115	99	0	0	104	110	59
c8	SM fig	PM SM ali	n/a	n/a	n/a	n/a	n/a	n/a	n/a	4
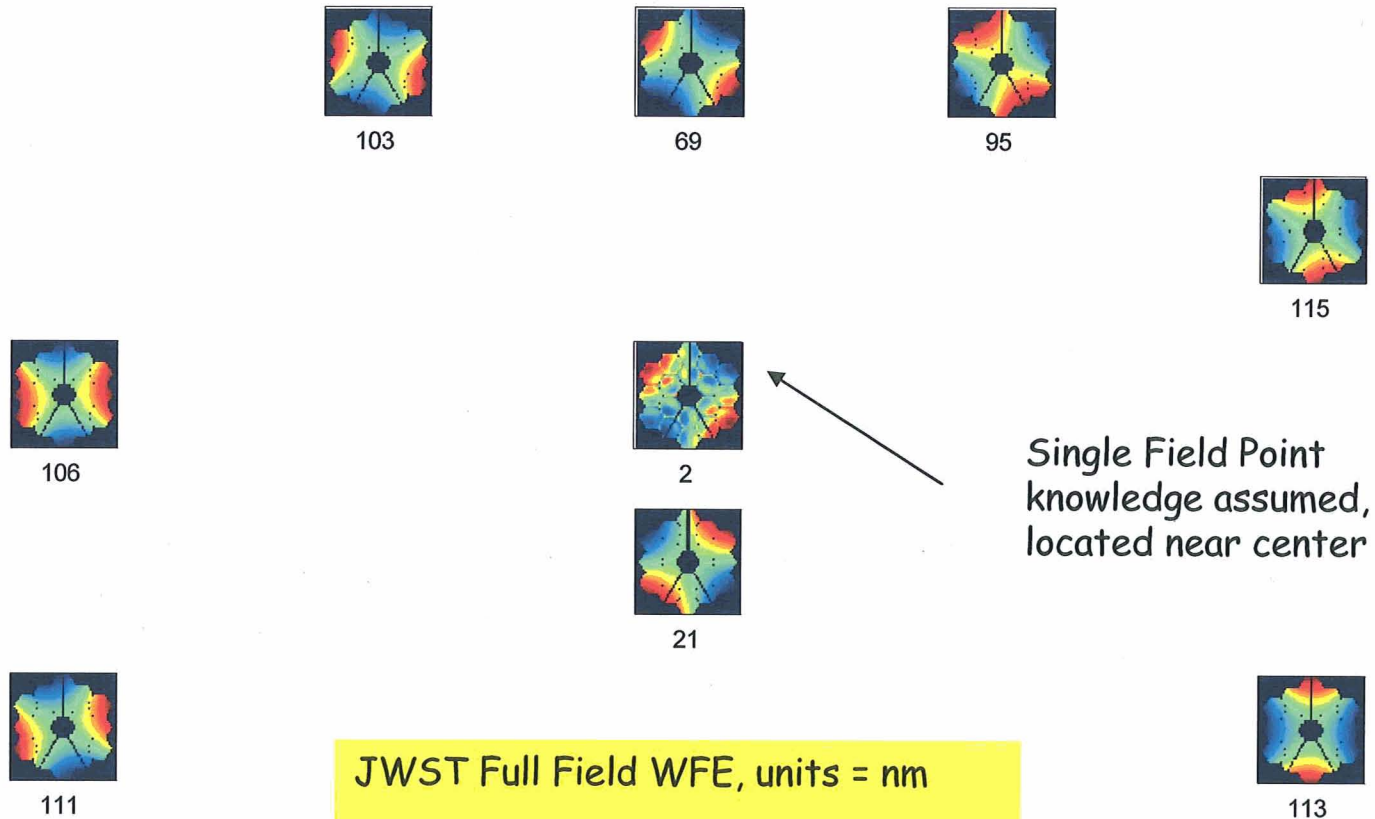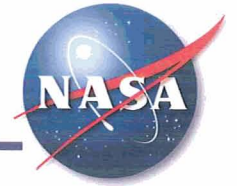
103

69

95

115

106

2

Single Field Point knowledge assumed, located near center

21

111

JWST Full Field WFE, units = nm

PM Align Error = 100 nm Astigmatism

PM Figure used to correct error

113

11

65

5

73

111

111

1

Single Field Point
knowledge assumed,
located near center

5

119

JWST Full Field WFE, units = nm

PM Align Error = 100 nm Astigmatism

SM alignment used to correct error

102

131

68

115

163

161

2

Single Field Point knowledge assumed, located near center

21

166

163
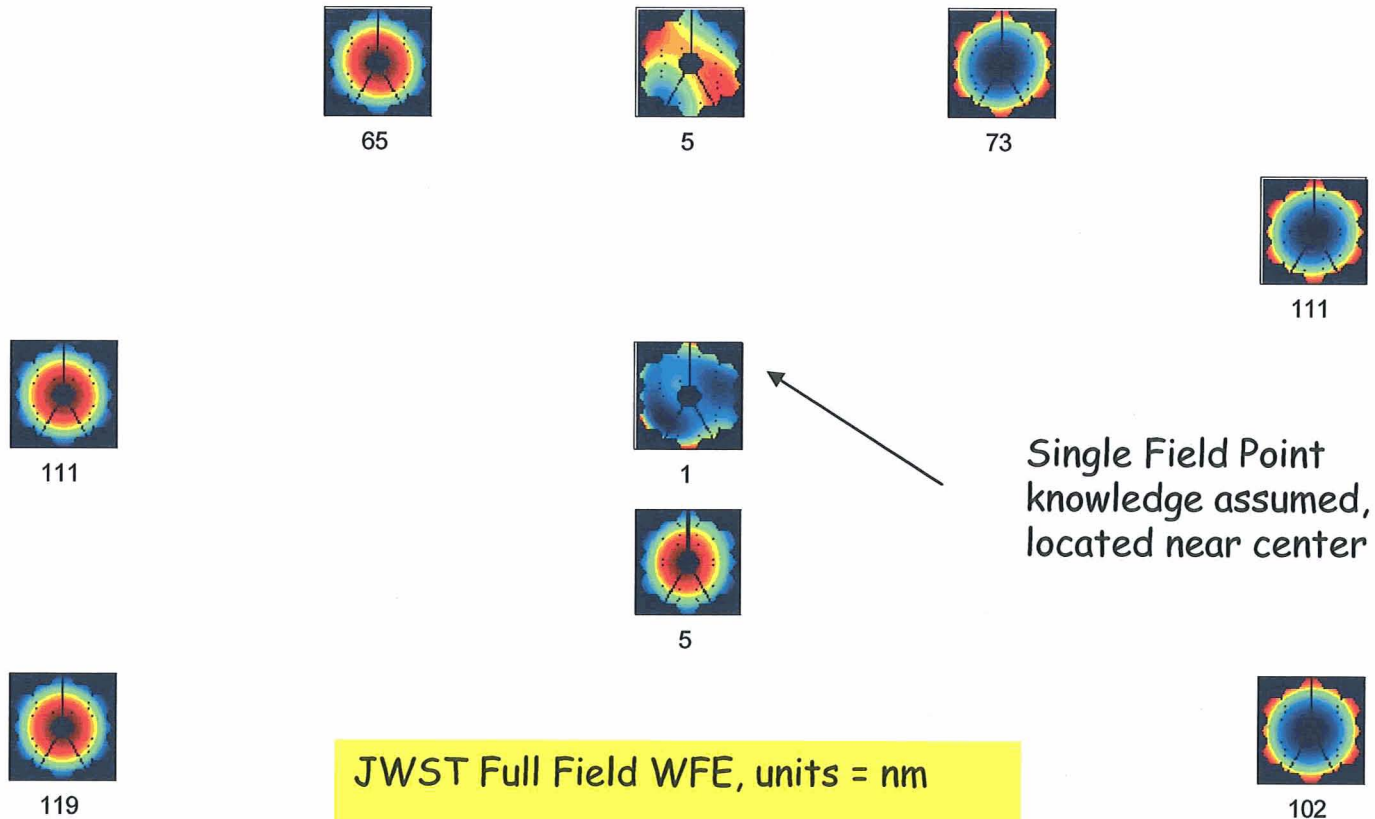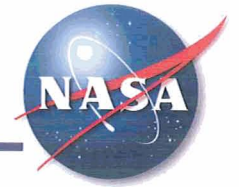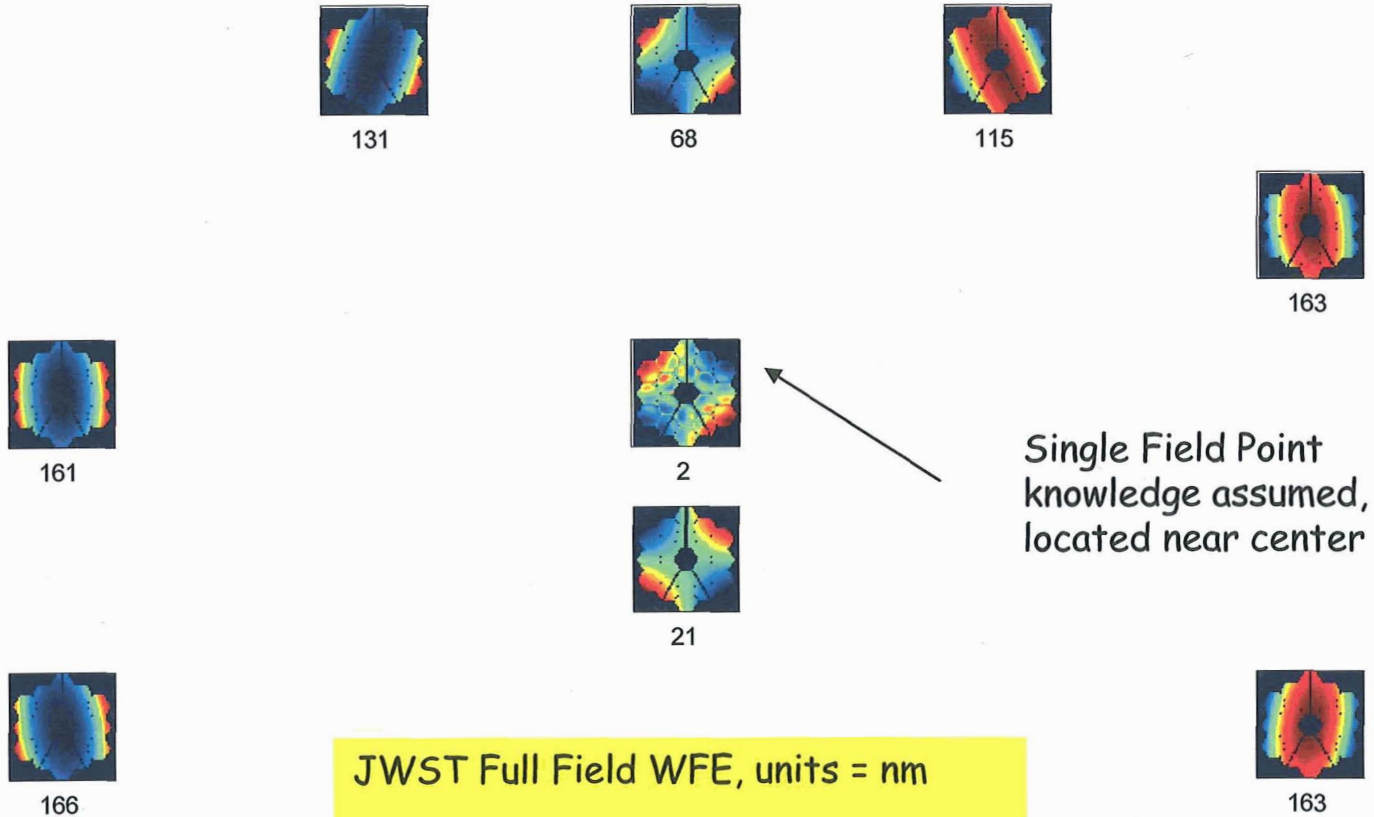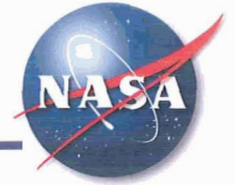
JWST Full Field WFE, units = nm

SM Align Error = 100 nm Astigmatism

PM figure used to correct error

13

133

69

113

162

161

2

Single Field Point
knowledge assumed,
located near center

21

165

164
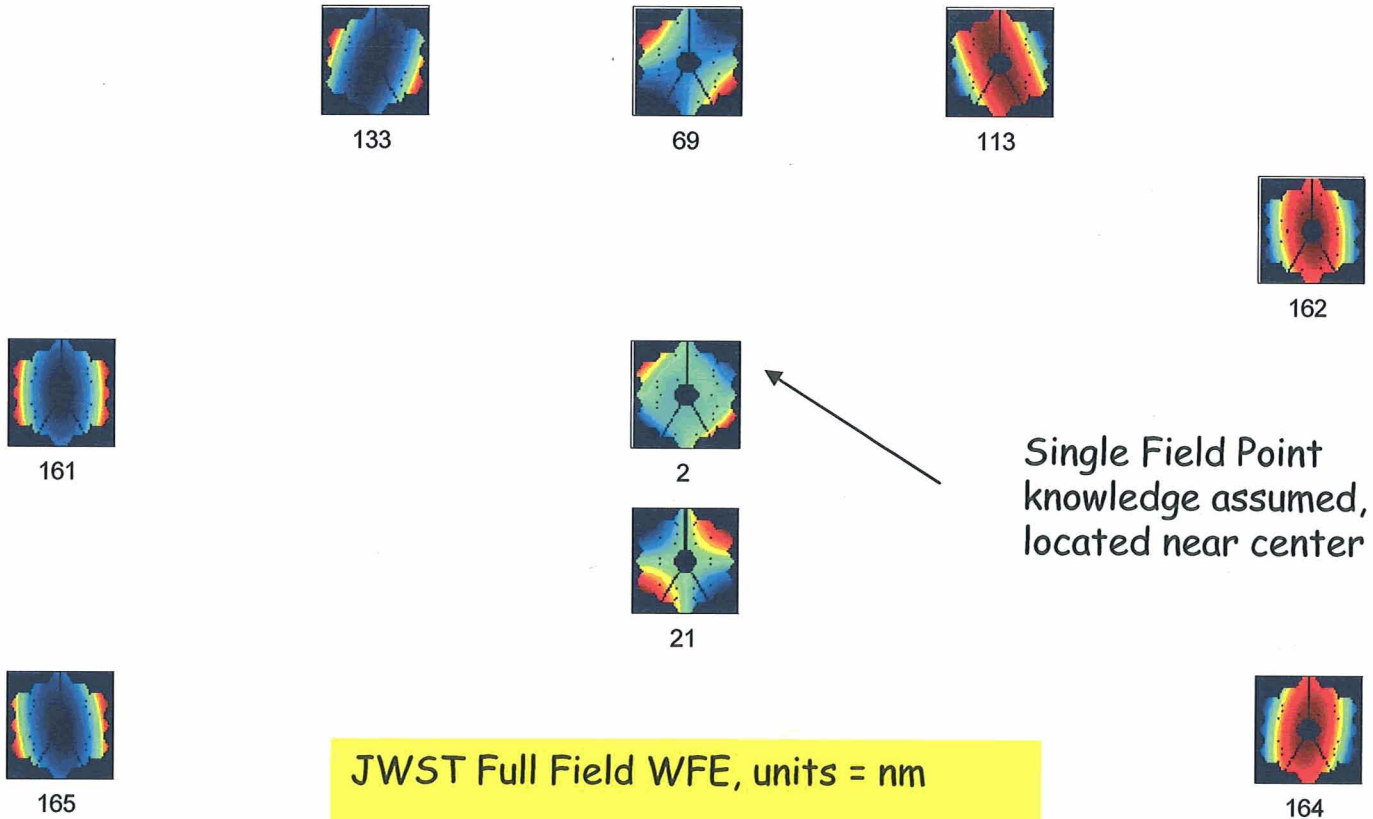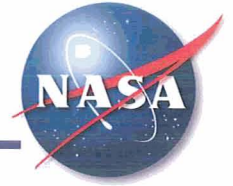
JWST Full Field WFE, units = nm

SM figure error = 100 nm Astigmatism

SM alignment used to correct error

	Power	Astig	Astig45	Coma	Coma90	Trefoil	Trefoil60	Spherical
PM ali PM fig	5	114	136	5	5	8	6	4
PM ali SM ali	0	14	12	1	1	1	1	0
SM ali PM ali	0	16	11	0	0	1	0	0
SM ali PM fig	4	116	99	4	5	8	5	3
SM fig PM ali	0	113	102	2	1	104	110	59
SM fig PM fig	0	1	1	17	20	19	26	23
SM fig SM ali	0	115	99	0	0	104	110	59

16
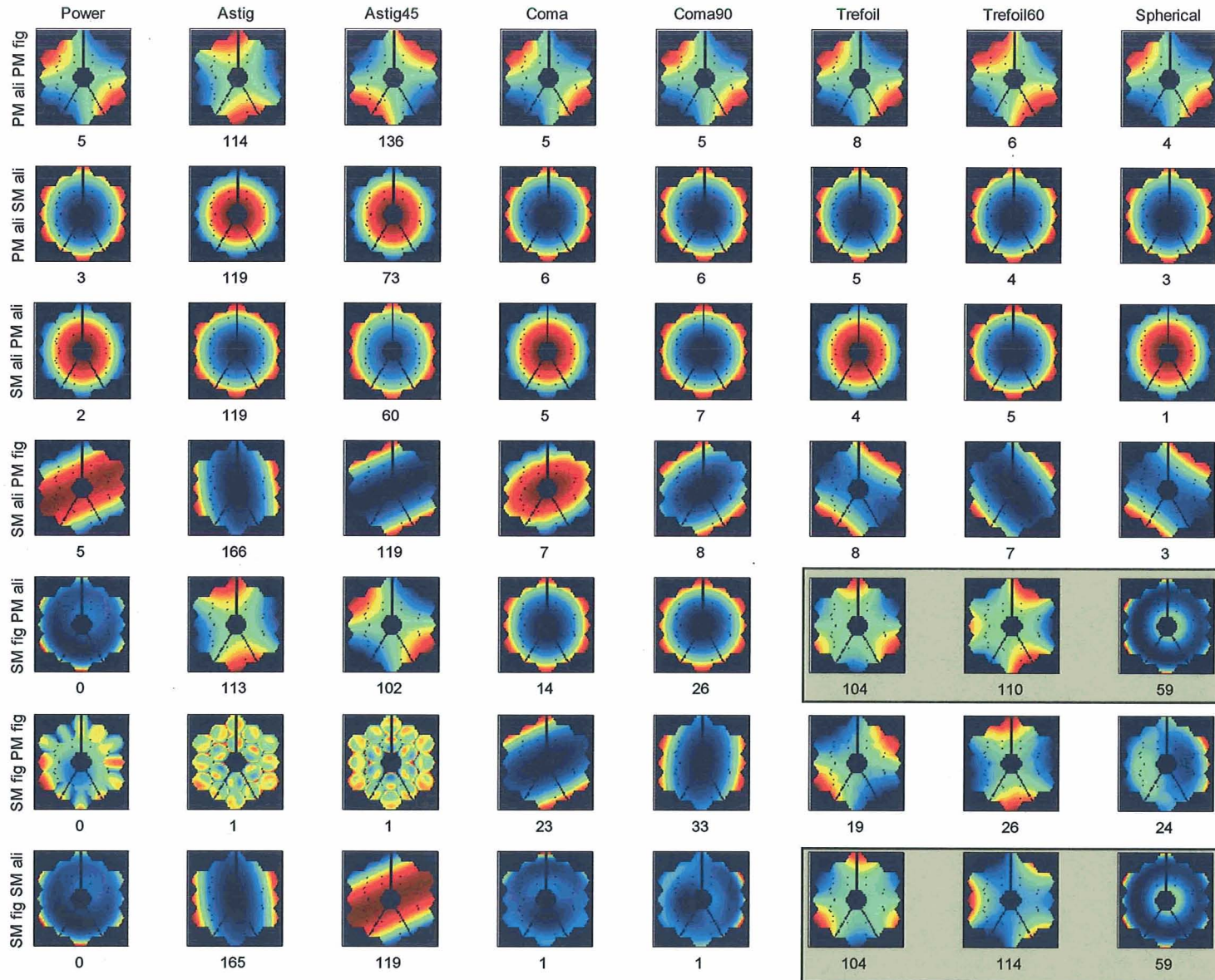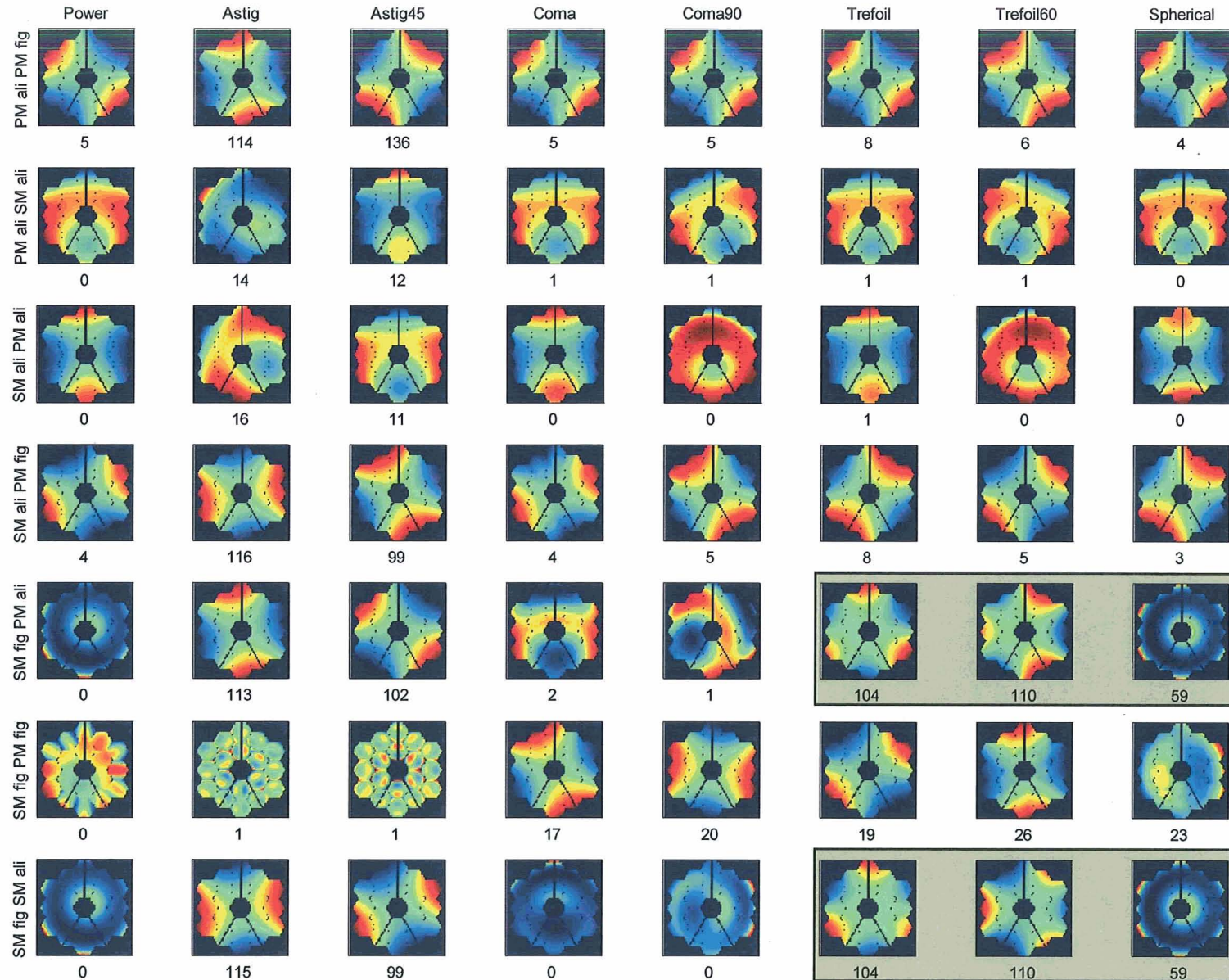
Field impact from compensation (+/- 1 arcmin FOV)

1 ARCMIN HFOV WORST CASE in RMS WFE (nm)

	ERROR	COMP	Power	Astig 45	Astig	Coma	Coma 90	Trefoil	Trefoil 60	Spherical
c1	PM ali	PM fig	1	13	16	1	1	1	1	1
c2	PM ali	SM ali	1	13	16	1	1	1	1	1
c3	SM ali	PM ali	1	14	13	1	1	1	1	1
c4	SM ali	PM fig	1	19	18	2	1	1	1	1
c5	SM fig	PM ali	0	14	13	3	3	98	97	54
c6	SM fig	PM fig	0	1	1	4	4	3	4	5
c7	SM fig	SM ali	0	19	18	1	0	98	97	54
c8	SM fig	PM SM ali	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1

1 ARCMIN HFOV WORST CASE at BEST FOCUS in RMS WFE (nm)

	ERROR	COMP	Power	Astig 45	Astig	Coma	Coma 90	Trefoil	Trefoil 60	Spherical
c1	PM ali	PM fig	1	13	16	1	1	1	1	1
c2	PM ali	SM ali	0	2	2	0	0	0	0	0
c3	SM ali	PM ali	0	2	2	0	0	0	0	0
c4	SM ali	PM fig	1	13	12	1	1	1	1	0
c5	SM fig	PM ali	0	14	13	1	0	98	97	54
c6	SM fig	PM fig	0	1	1	2	2	3	4	4
c7	SM fig	SM ali	0	13	12	0	0	98	97	54
c8	SM fig	PM SM ali	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1

Concluding Remarks
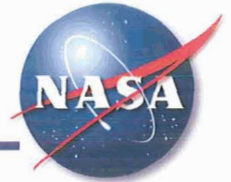
- The resulting "starting" errors will naturally be a mix of aberrations, therefore these numbers represent extreme cases for a single mode of error

- Field knowledge is important for deciding upon the proper compensation

- JWST Commissioning Alignment Algorithms are currently being developed

Any Questions?