Towards an overall astrometric error budget with MICADO-MCAO

G. Rodeghiero, J.U. Pott, D. Massari, M. Fabricius, C. Arcidiacono,
F. Cortecchia, G. Fiorentino, M. Lombini

Overview

- Relative astrometry with ELTs
- E-ELT + MAORY + MICADO
- Monte Carlo simulations
- Distortion sensitivity analysis
- Worst offenders for astrometry
- Strategies for MICADO astrometry

Relative Astrometry with ELTs

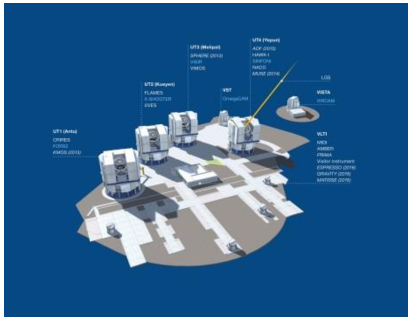
VISION -> Relative astrometry at **50 µas** level

$$\sigma = \frac{FWHM}{SNR}$$

FWHM → VLT / 5

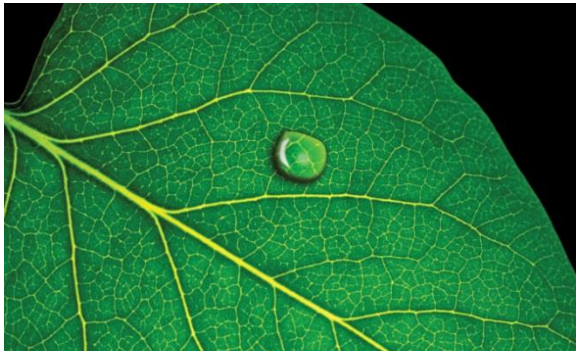
SNR → 25 x VLT

$\sigma_{\mathrm{ELTs}} \approx \sigma_{\mathrm{8m\ class}}/5$

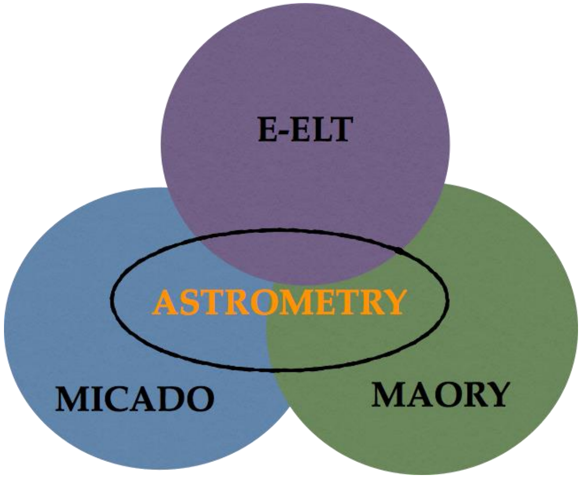


Telescopes **5** times bigger
smaller *FWHM* & higher *SNR*
BUT
stability issues

Distortion(t)

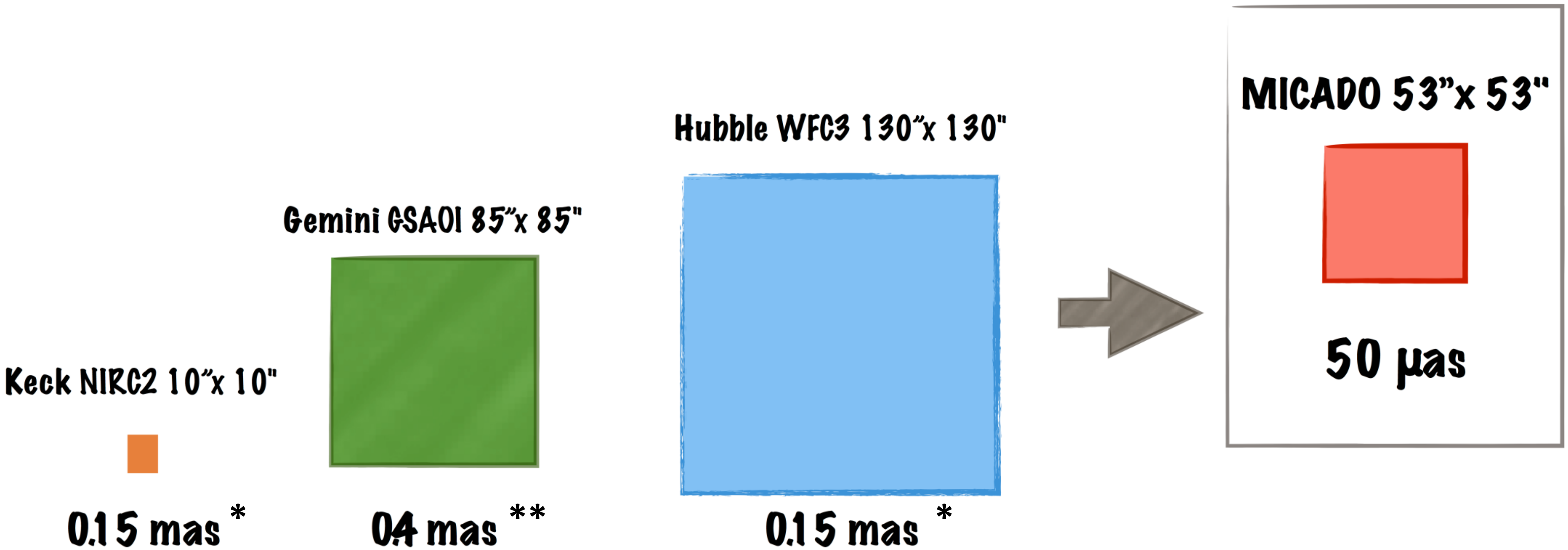


Relative Astrometry with ELTs



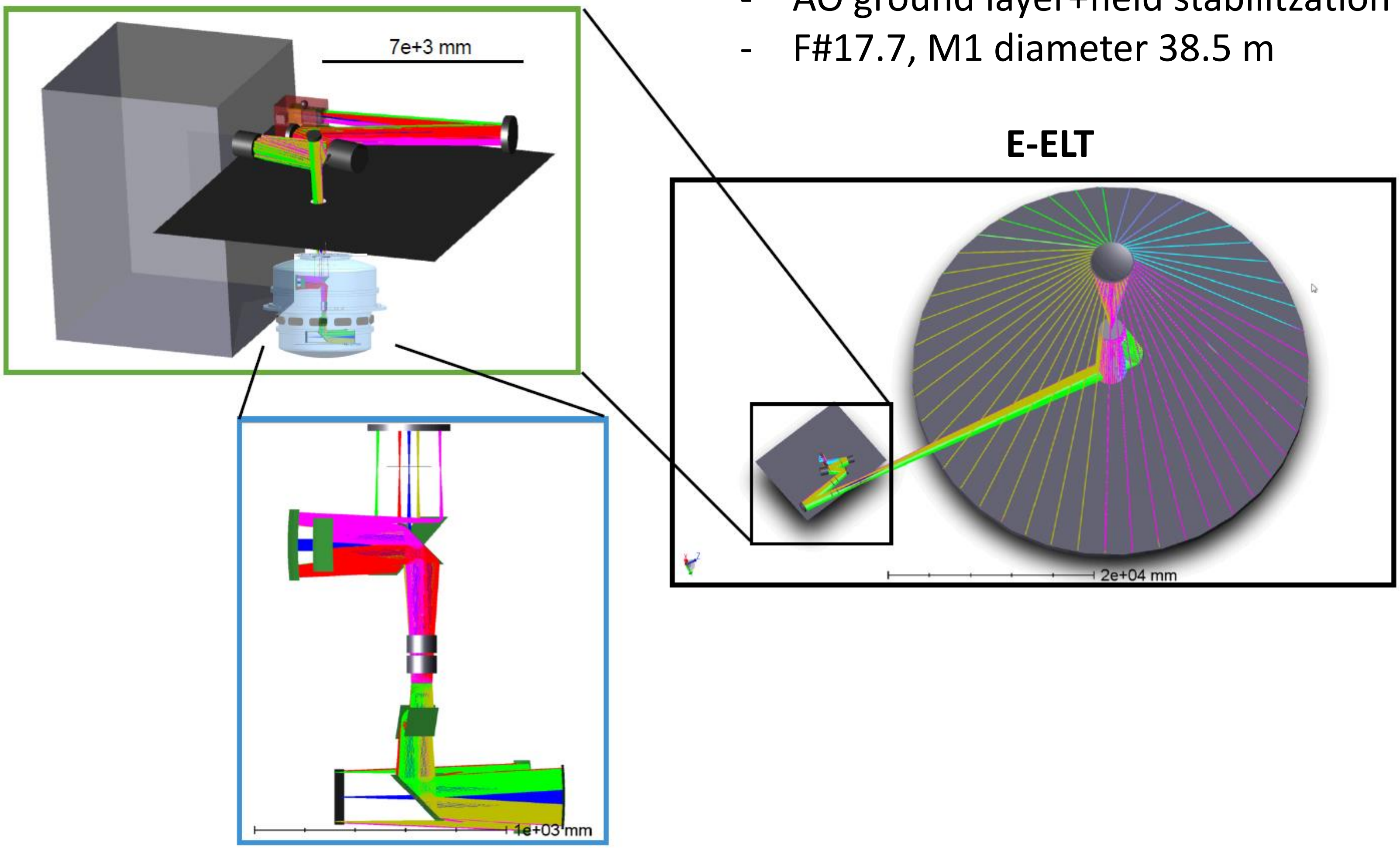
- Current instrument astrometry noise floor **0.15-0.4** mas
- NIRC2 **SCAO**
- WFC3 Space
- GeMS **MCAO**

(*) Lu, 2014, (**) Neichel, 2014



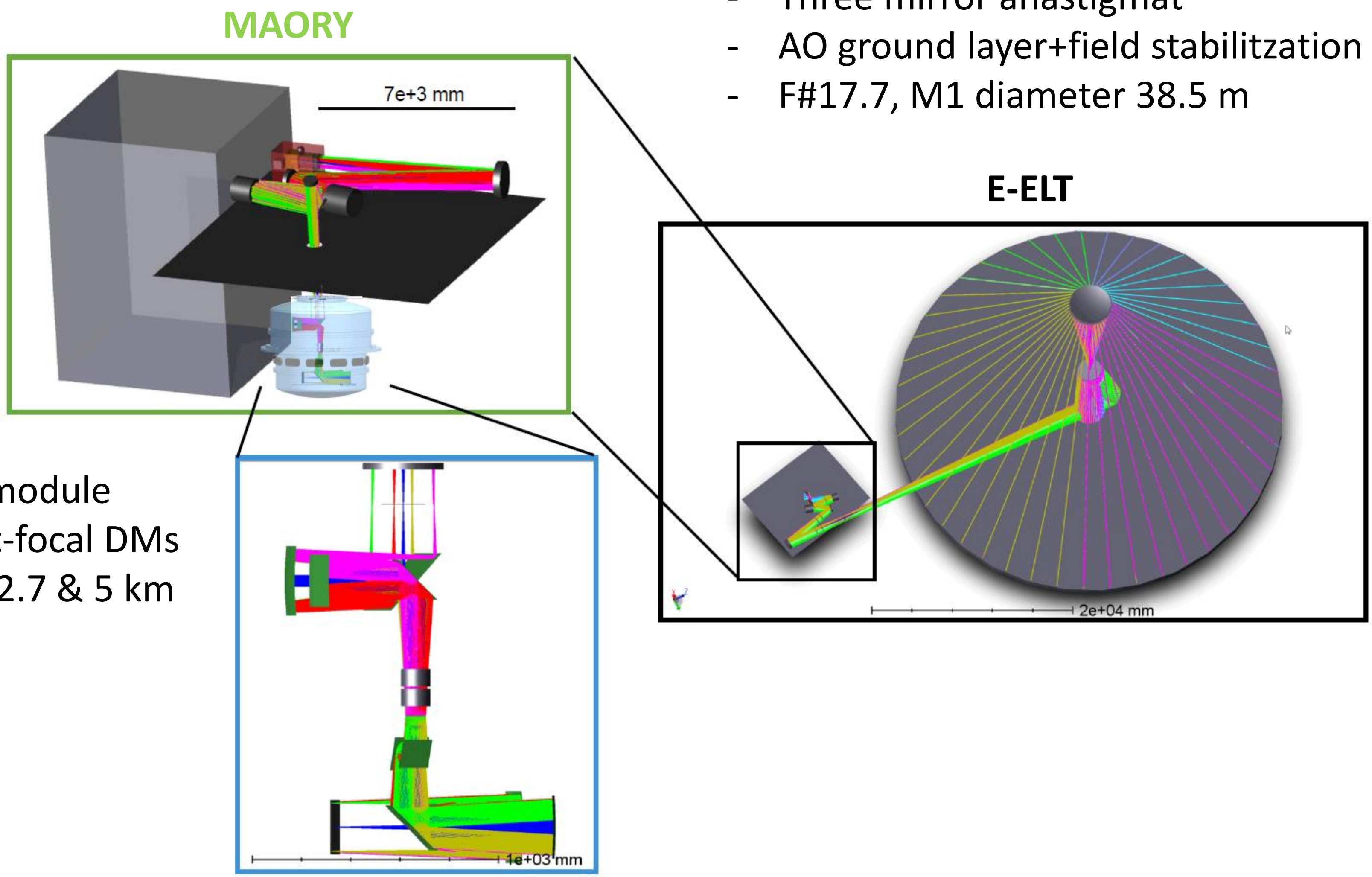
E-ELT+MAORY+MICADO

- Three mirror anastigmat
- AO ground layer+field stabilitzation
- F#17.7, M1 diameter 38.5 m



E-ELT+MAORY+MICADO

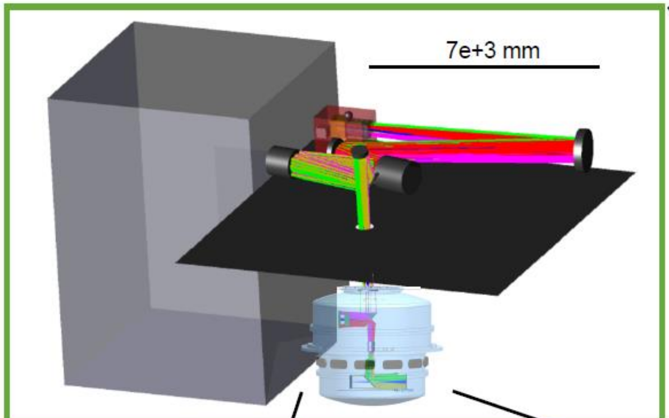
- Three mirror anastigmat
- AO ground layer+field stabilitzation
- F#17.7, M1 diameter 38.5 m



- MCAO module
- 1-2 Post-focal DMs
- DM@ 12.7 & 5 km
- F#17.7

E-ELT+MAORY+MICADO

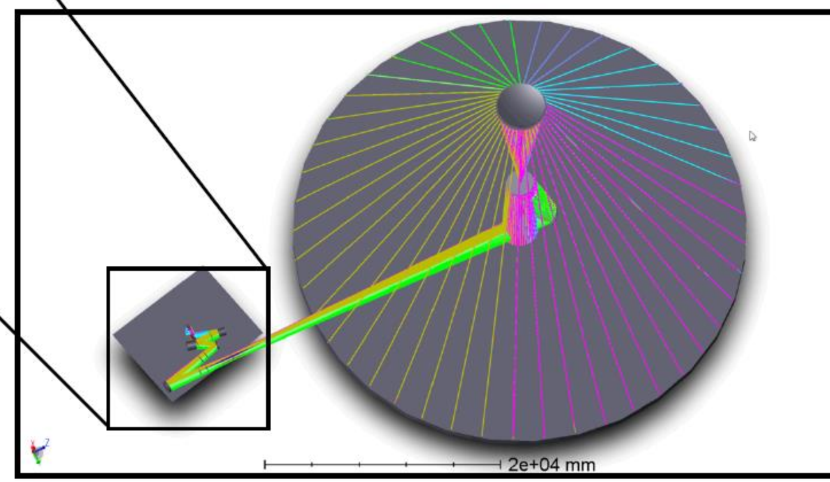
MAORY

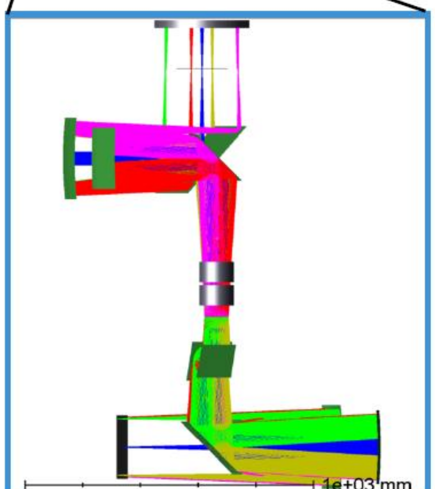


- MCAO module
- 1-2 Post-focal DMs
- DM@ 12.7 & 5 km
- F#17.7

- Three mirror anastigmat
- AO ground layer+field stabilitzation
- F#17.7, M1 diameter 38.5 m

E-ELT

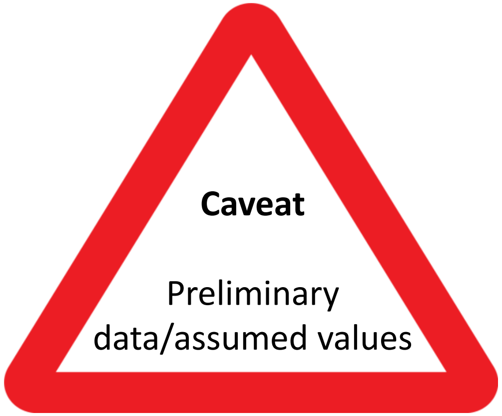




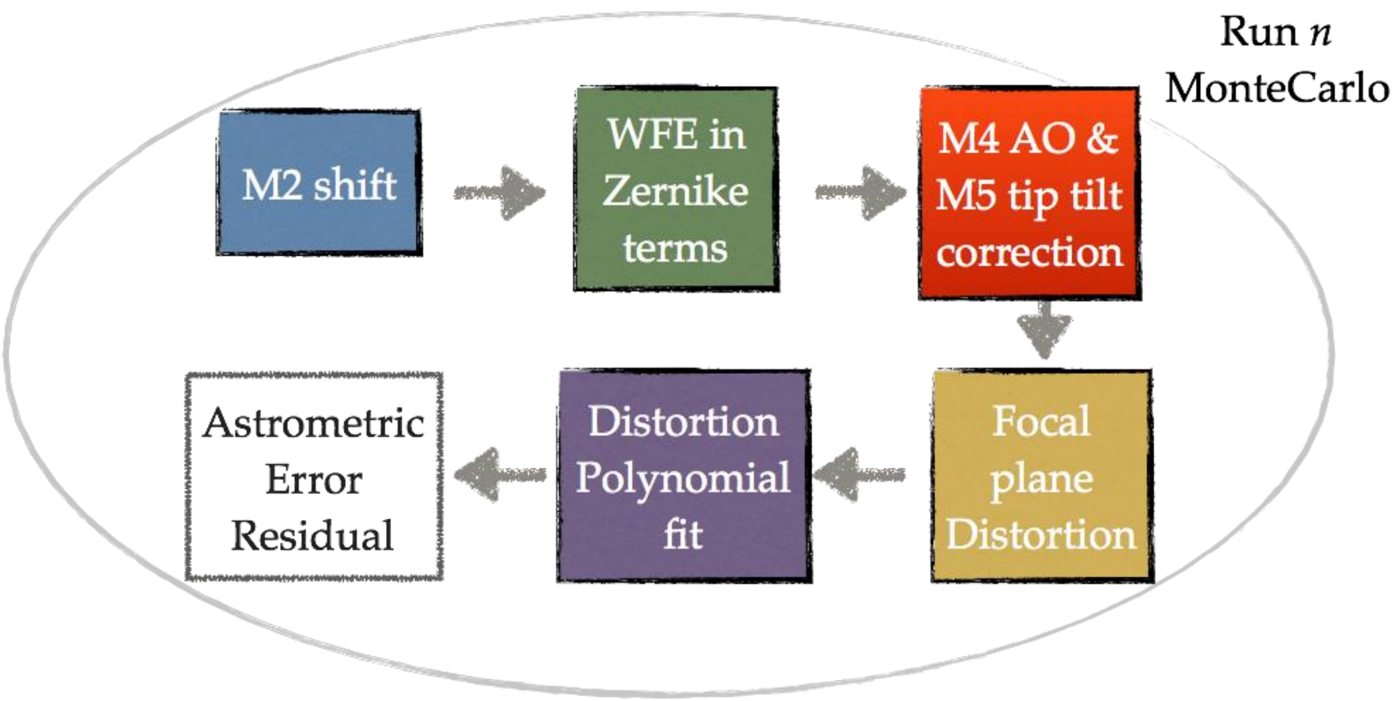
MICADO

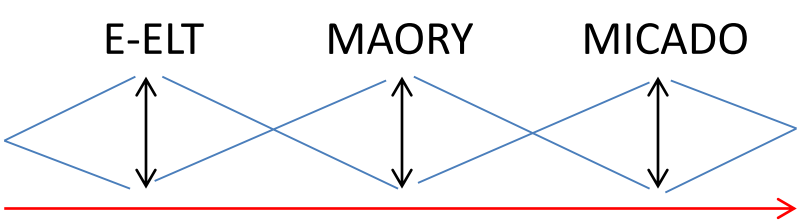
- Camera & spectrometer
- 2 TMAs, only fixed mirrors
- Cryogenic, gravity invariant
- FoV 53”, pixel scale 1.5-4.5 mas

MC tolerances approach



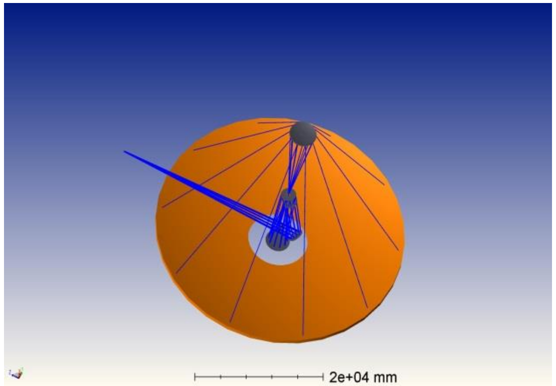
- OpticStudio (Zemax) ZOS-API using Matlab

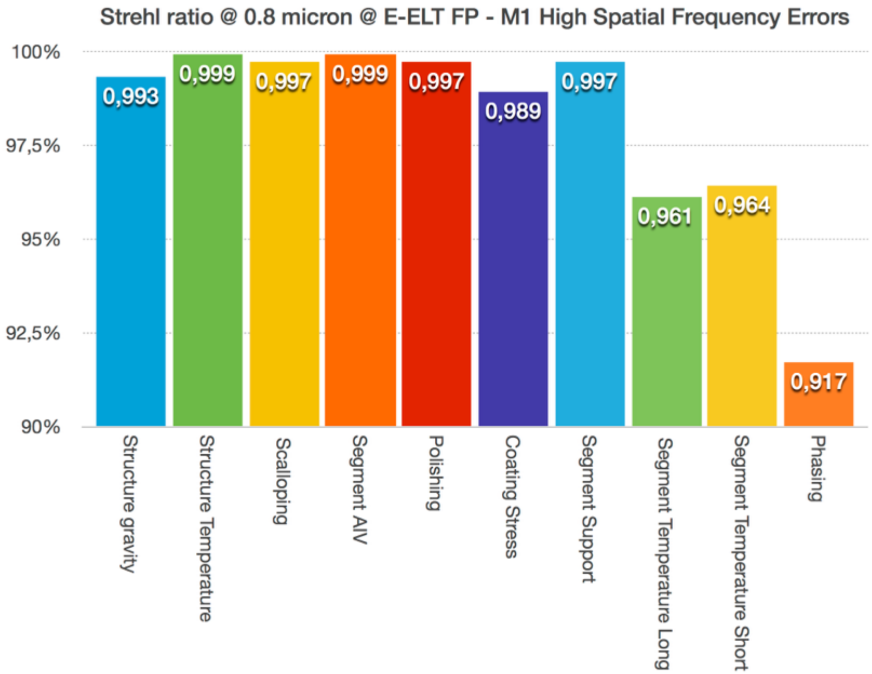




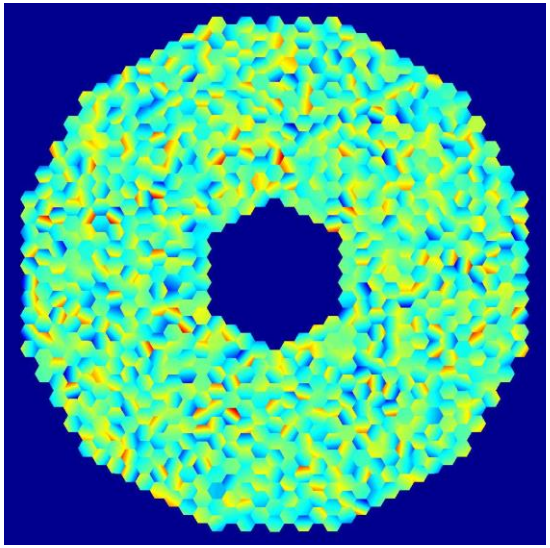
M1 Tolerances

- High spatial frequency errors
- Decrease of the Strehl ratio
- M1 at entrance pupil -> no differential distortion in FoV





Phasing errors

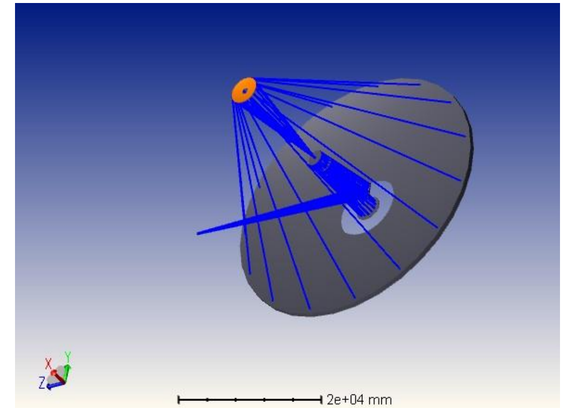


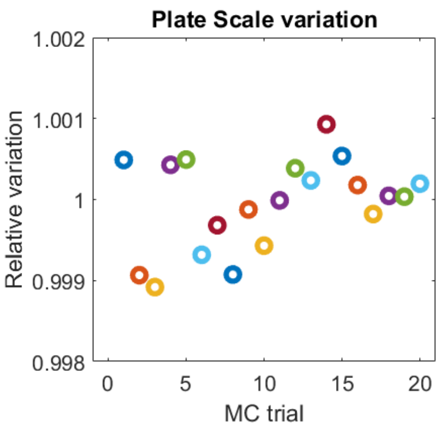
ESO dataset, Marchetti 2015

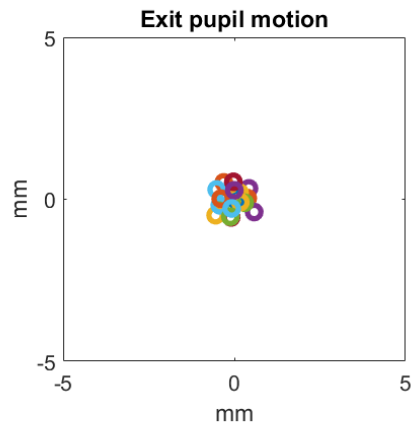
M2 Tolerances

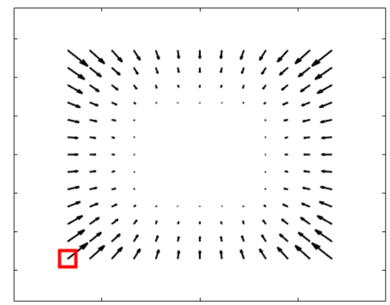
-0.1 mm < dx, dy, dz < +0.1 mm

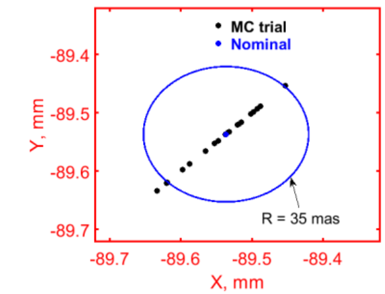
-0.01° < θx, θy < +0.01° (Mueller, 2014 - Cayrel, 2012)

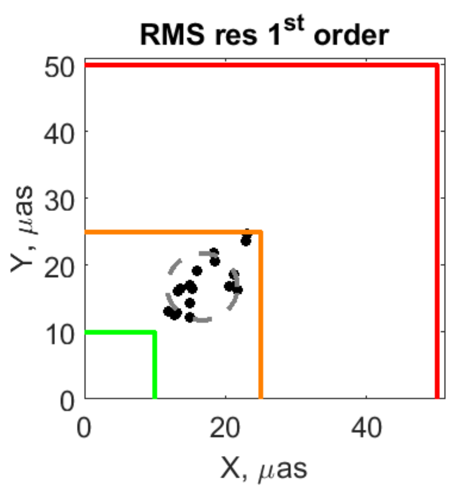


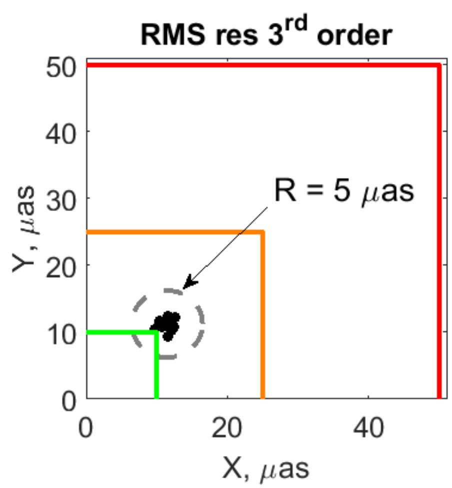


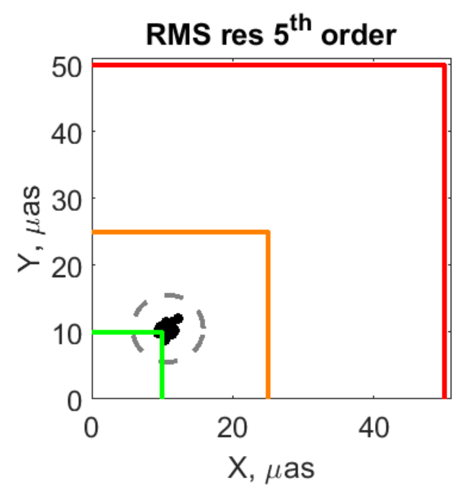




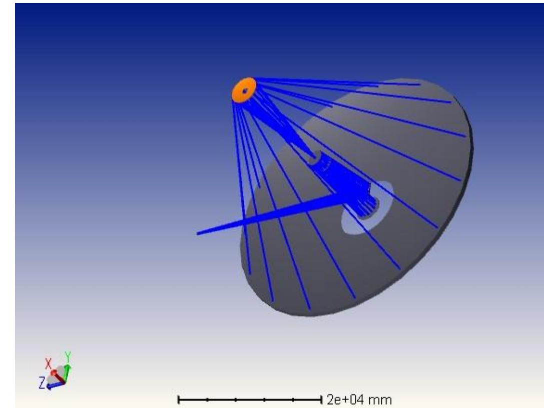






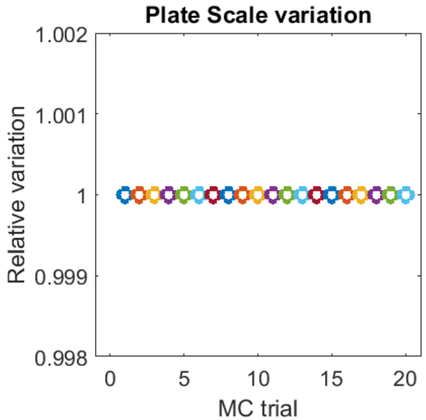


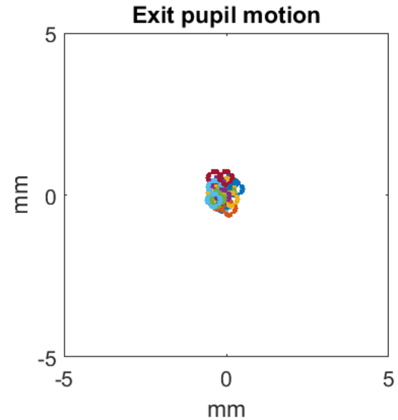
M2 Tolerances

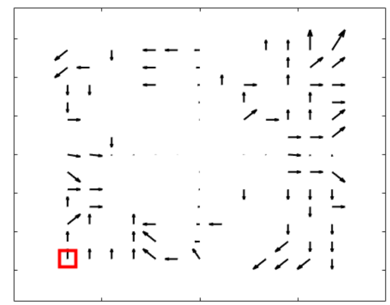


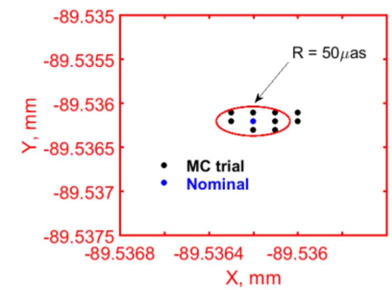
-0.1 mm < dx, dy < +0.1 mm -> **dz = 0**

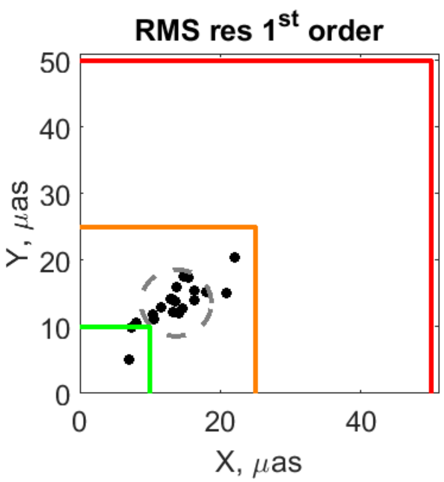
-0.01° < θx, θy < +0.01°

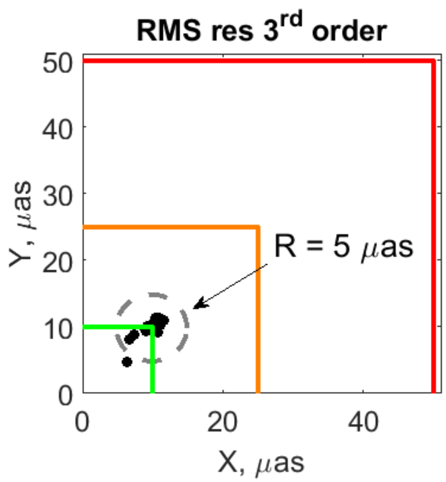


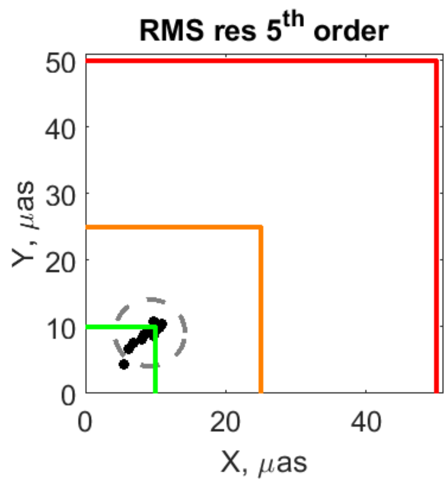




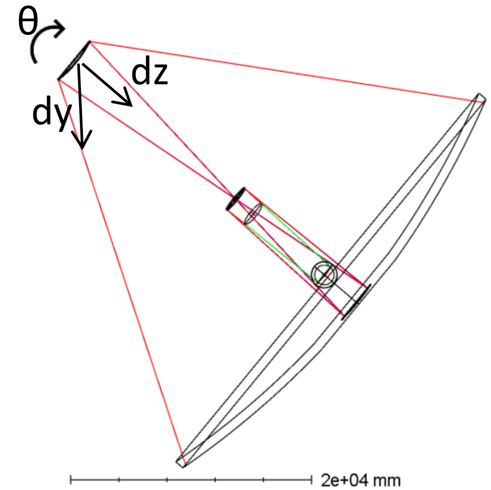






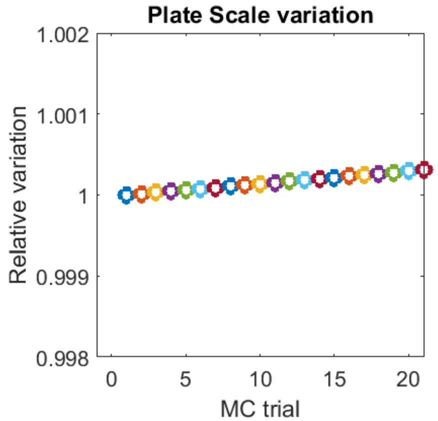


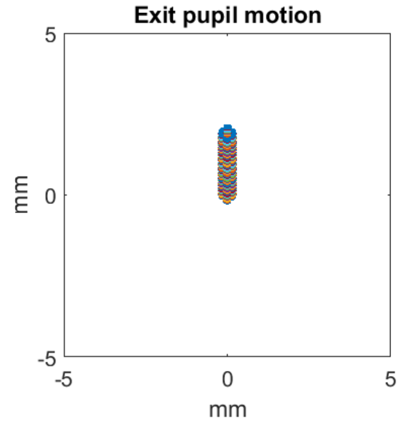
M2 Low Order Optimization

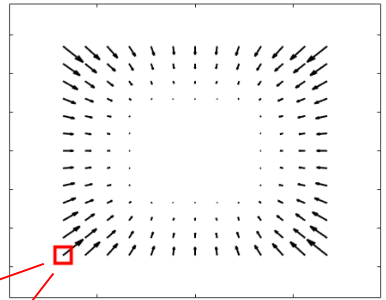


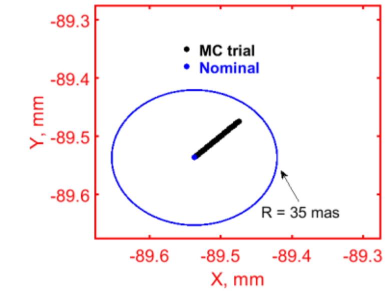
dy, dz = 0 → 100 µm

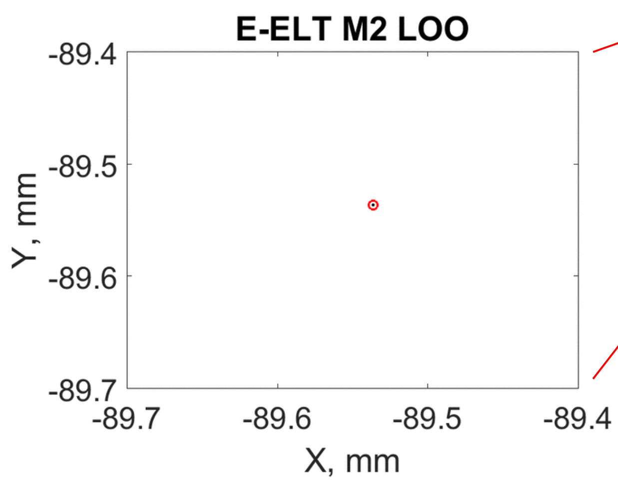
θ = 0 → 0.01° (Mueller, 2014)

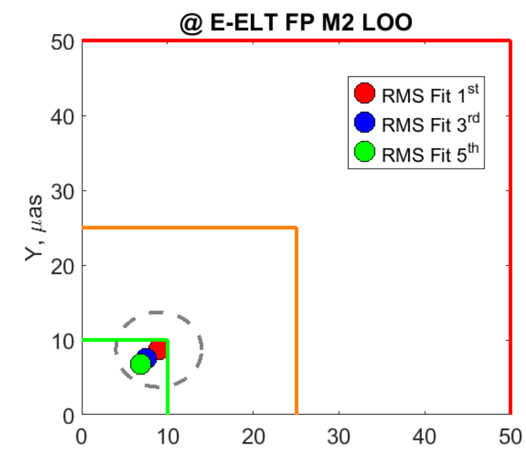






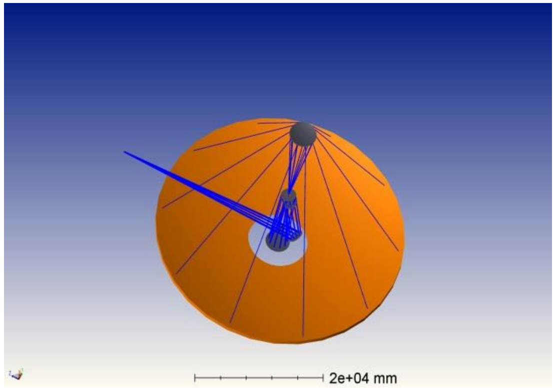


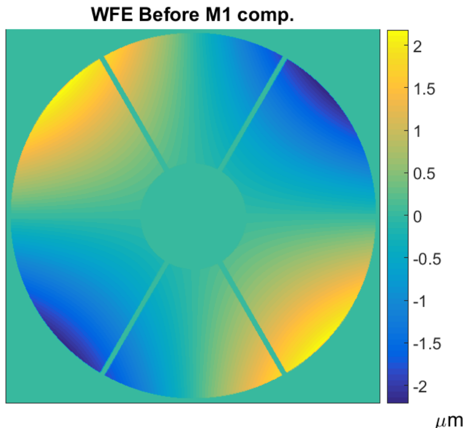


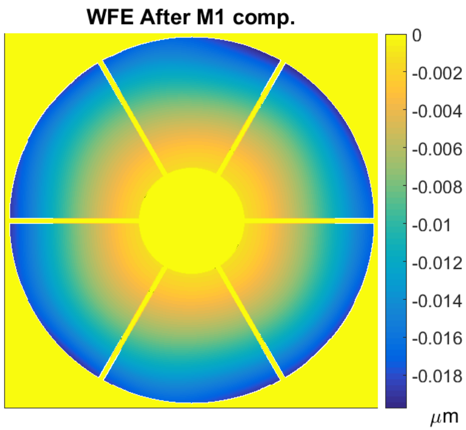


M2 shape aberrations

RMS = 506 nm astigmatism on M2 (Mueller, 2014)
M1 phasing compensation of M2 deformation

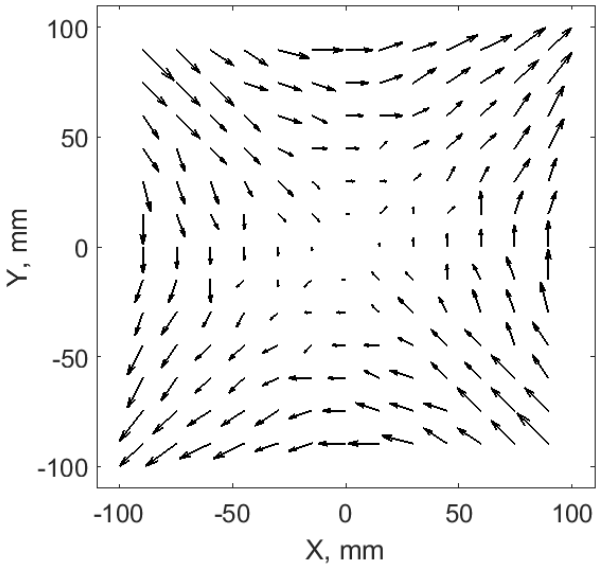


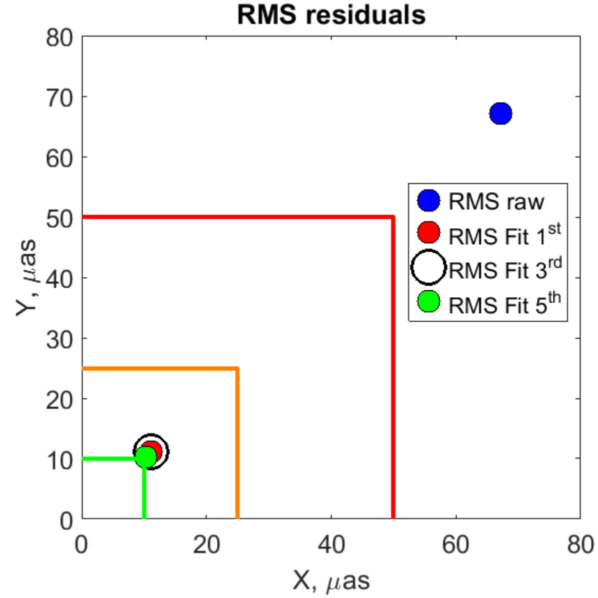




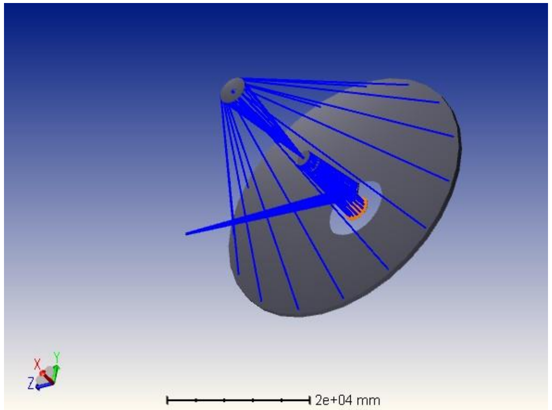
At exit pupil

Induced distortion



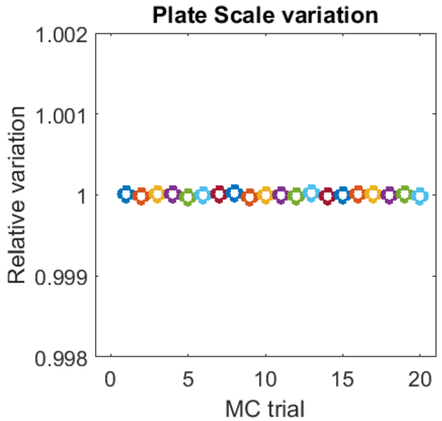


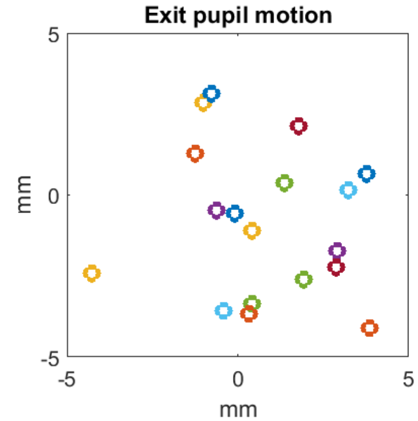
M3 Tolerances

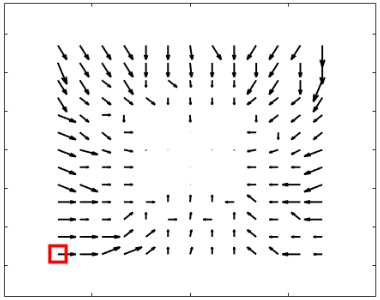


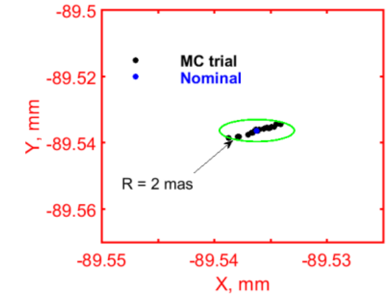
-0.1 mm < dx, dy, dz < $+0.1$ mm

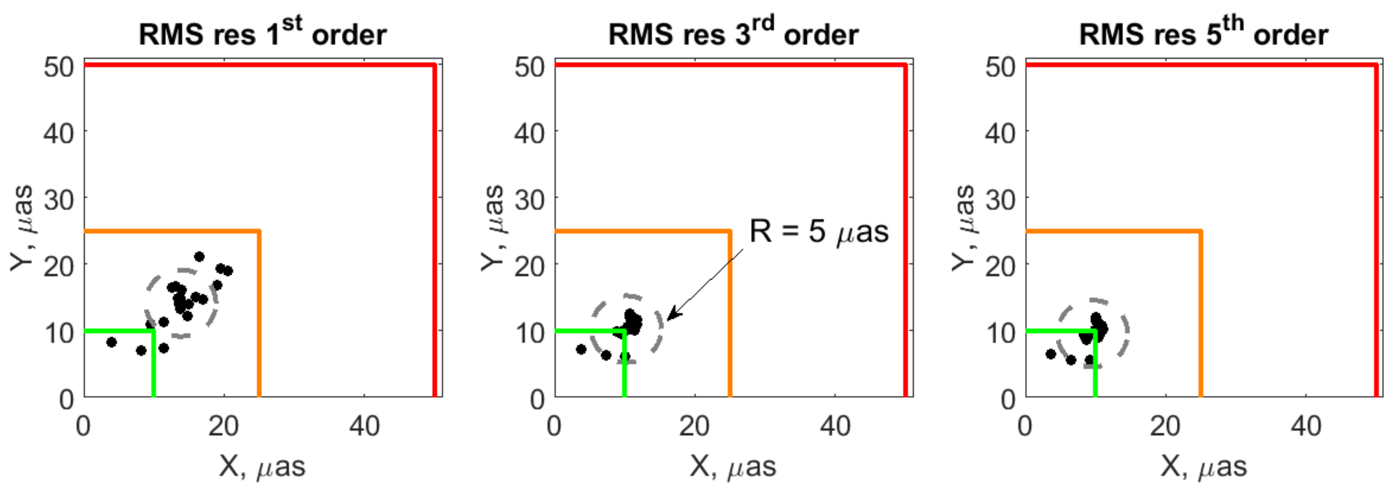
$-0.01^\circ < \theta x, \theta y < +0.01^\circ$ (Cayrel, 2012)







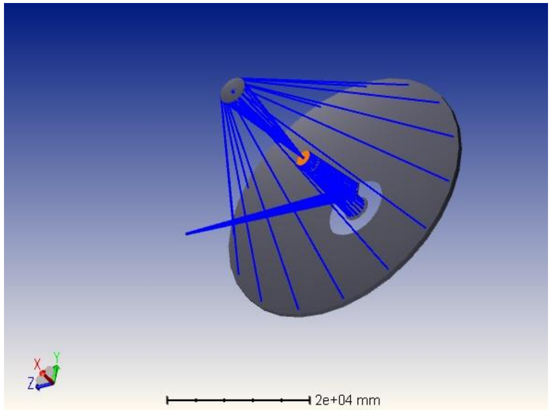


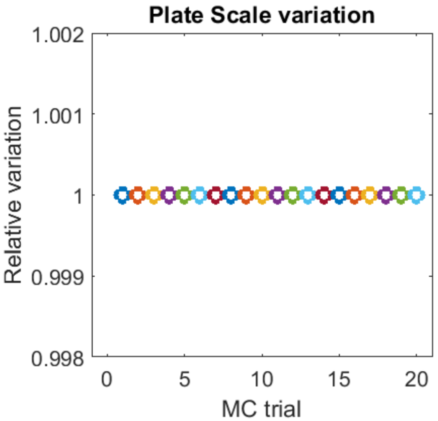


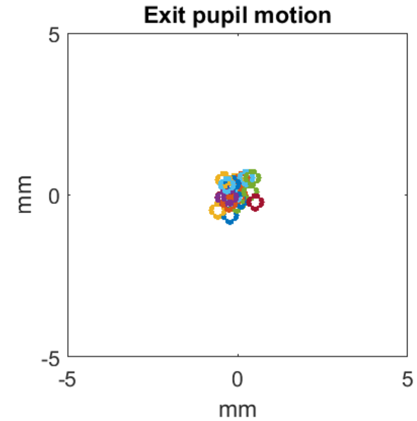
M4 Tolerances

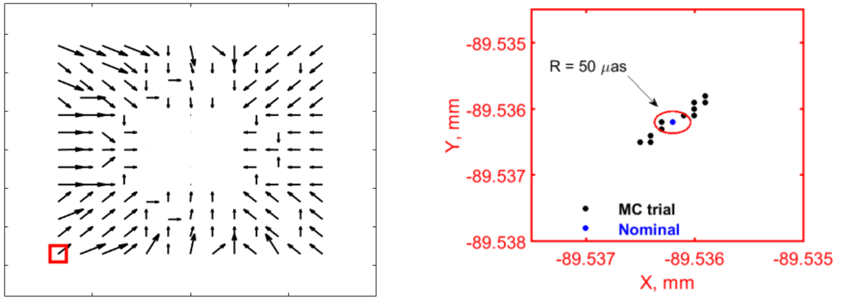
-0.1 mm < dx, dy, dz < +0.1 mm

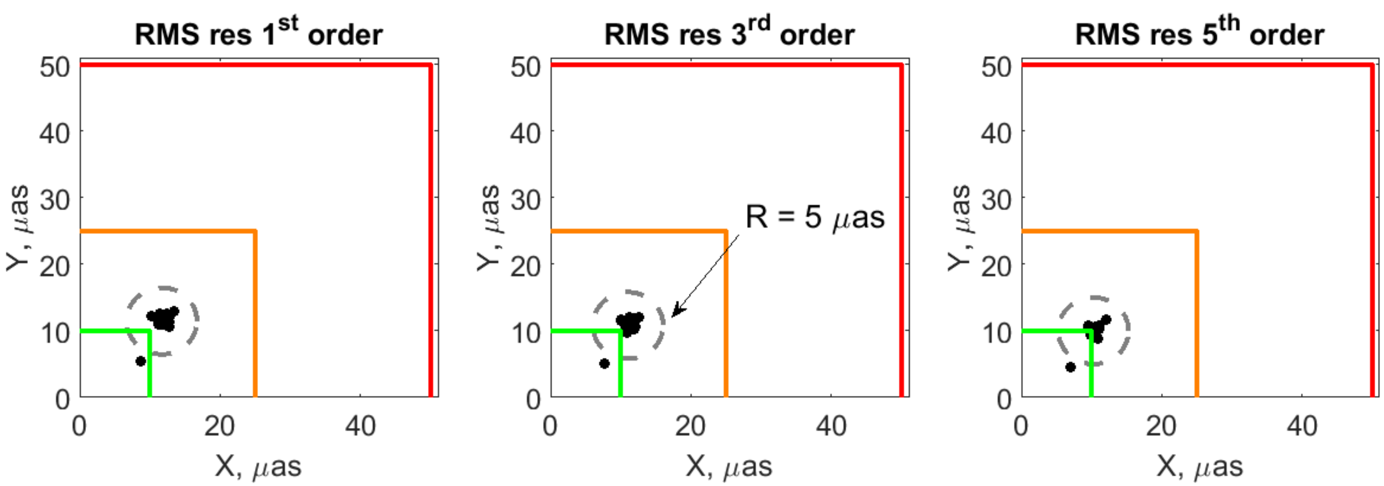
-0.01° < θx, θy < +0.01°



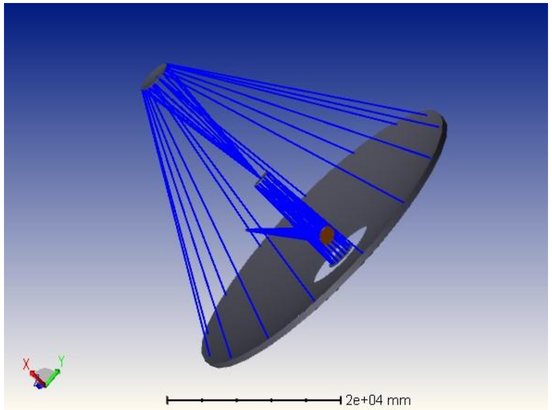






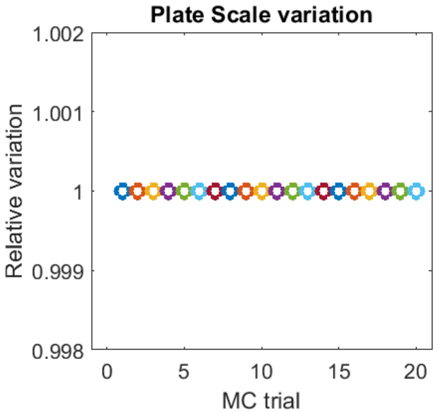


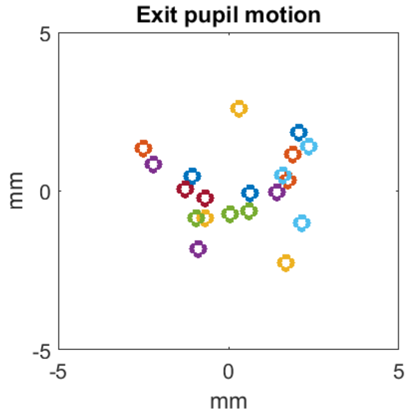
M5 Tolerances

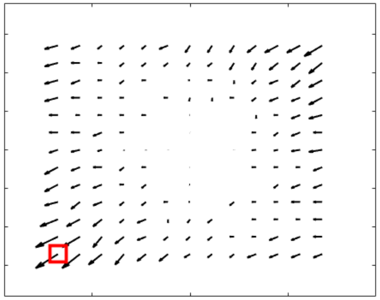


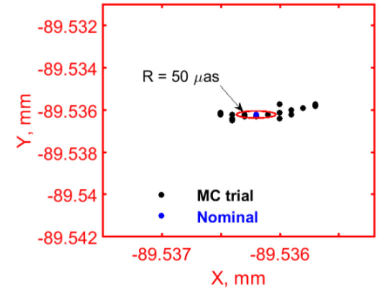
-0.1 mm < dx, dy, dz < +0.1 mm

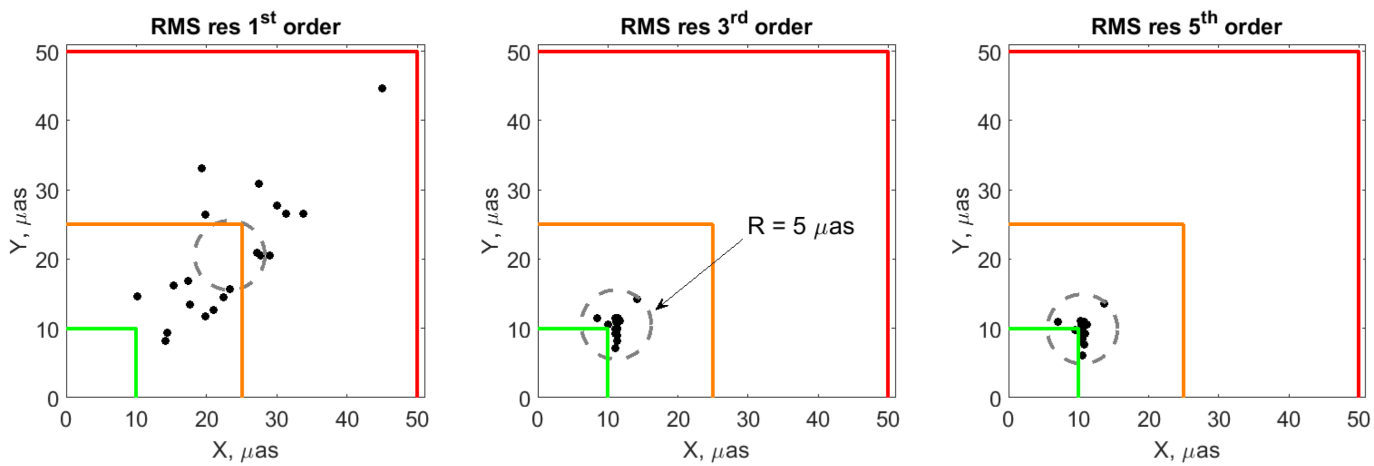
-0.01° < θx, θy < +0.01°





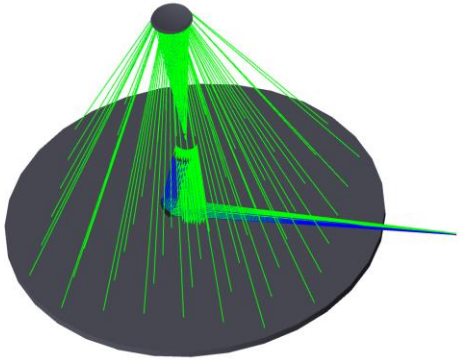


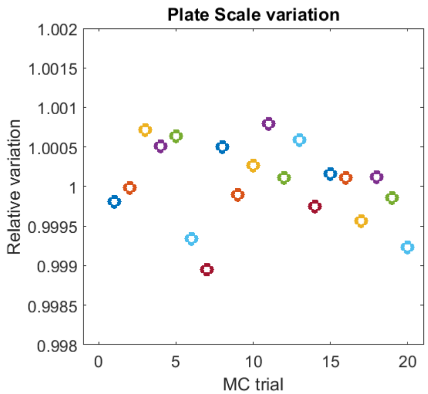


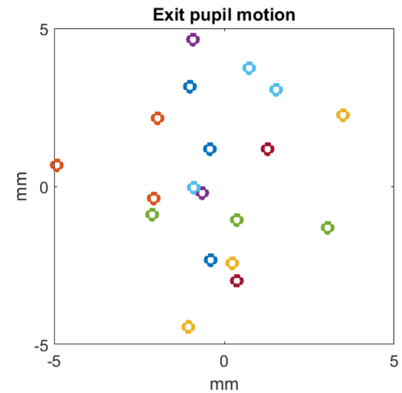


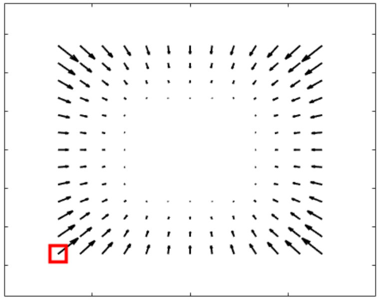
E-ELT Tolerances

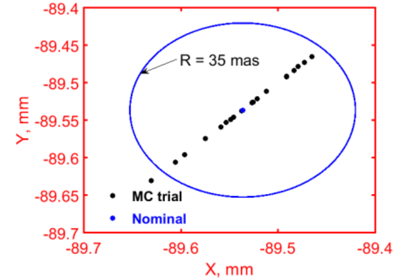
Combined tolerances on M2, M3, M4 & M5

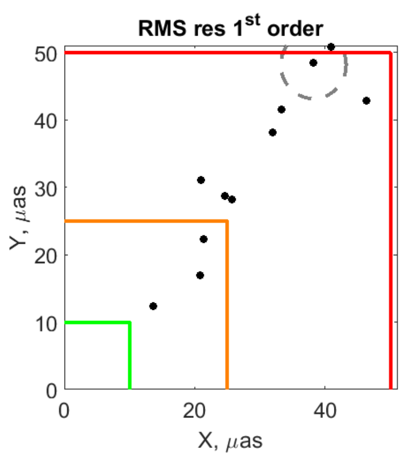


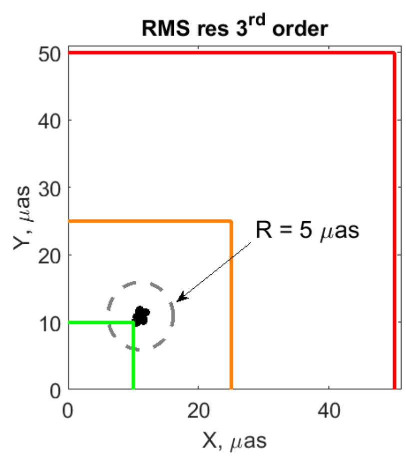


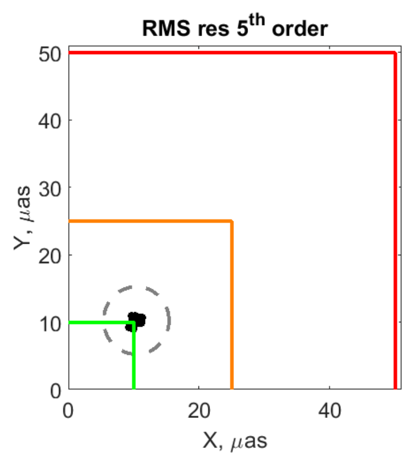










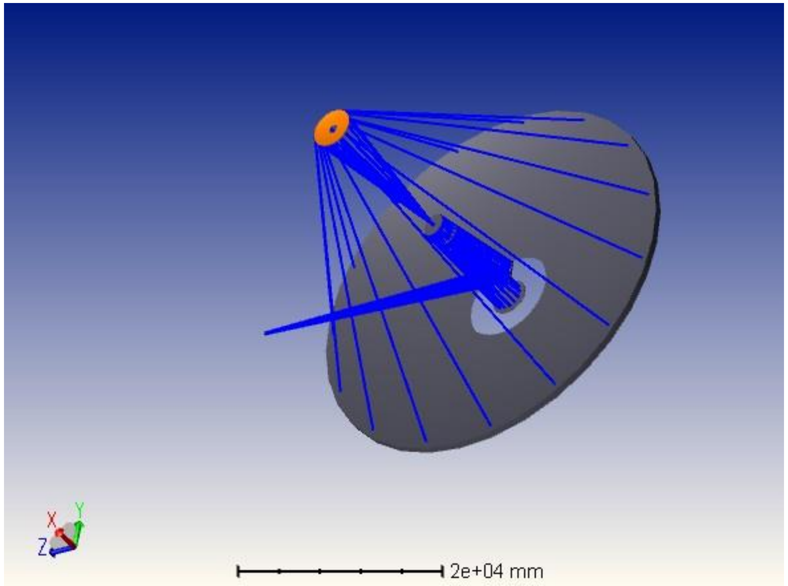


E-ELT Tolerances

- After 1st & 3rd order polynomial fit the astrometry residuals are **10-20 µas**
- 5th order polynomial fit -> no significant improvement

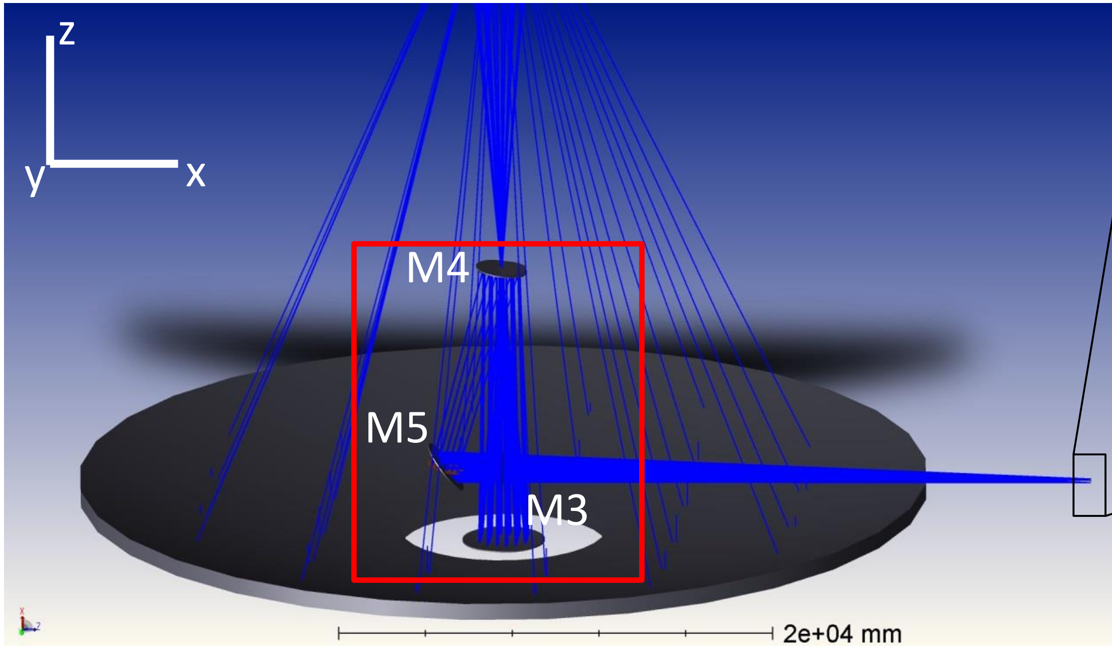
- 1st order distortions are dominated by plate scale variations
- The worst offender is **M2 axial drift**

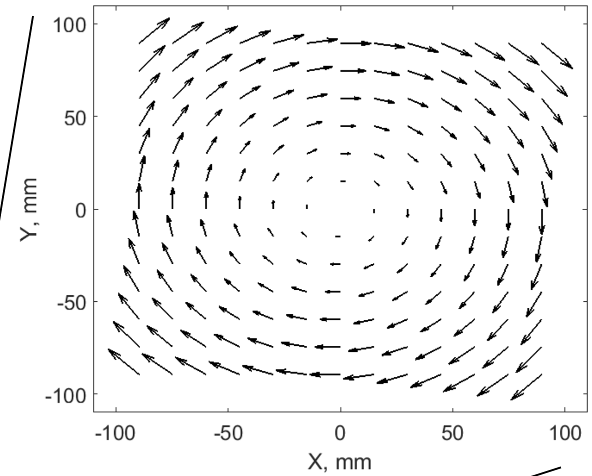
- The telescope distortions are calibrated **on sky**



M3-M4-M5 Field Rotation

The system M3-M4-M5 -> **k-mirror**



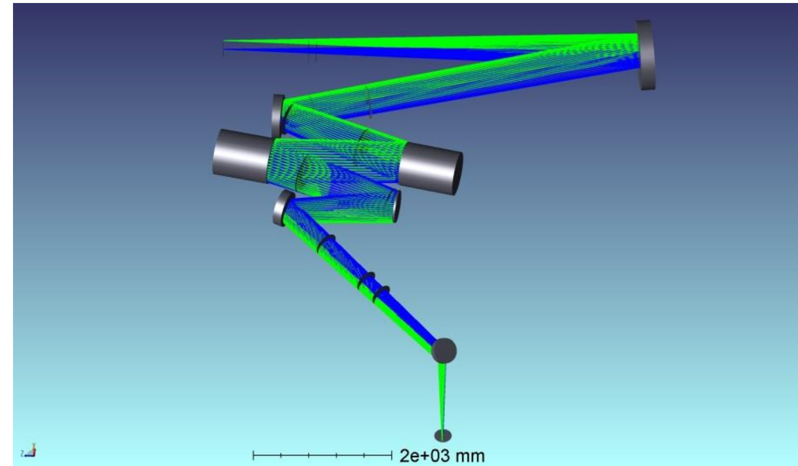


Tilt	M3	M4	M5
θx = 0.01°	-	3”	42”
θy= 0.01°	-	-	-
θz = 0.01°	-	10”	24”

Field stabilization M5 -> 100 Hz (Casalta, 2010)
- Seeing 1” M5 -> FR jitter 14”
- PSF shift FoV(30”) -> 2 mas

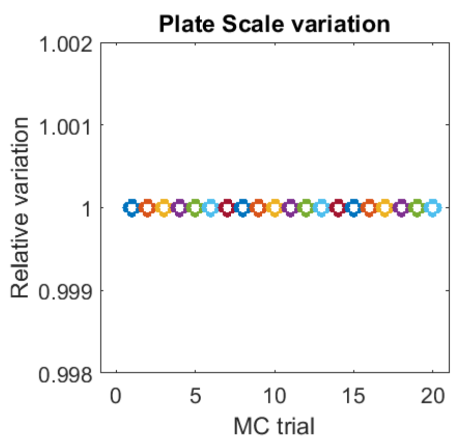
Field	H , mas	K, mas
On axis	7	10
Off axis	10	13

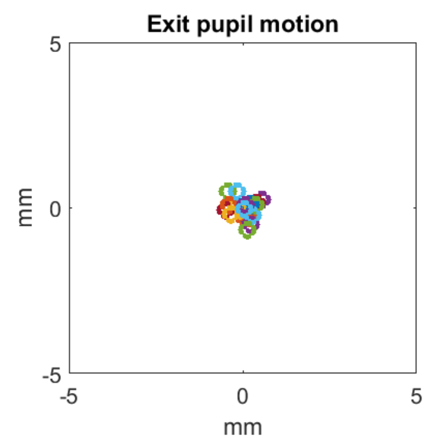
MAORY Tolerances

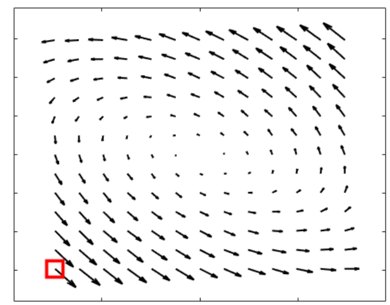


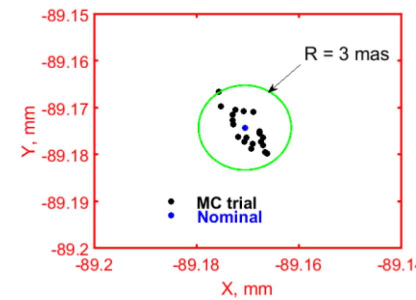
$-50\ \mu m < dx, dy, dz < +50\ \mu m + \Delta Bench(dT/h = 1°C)$

$-0.001° < \theta x, \theta y < +0.001°$

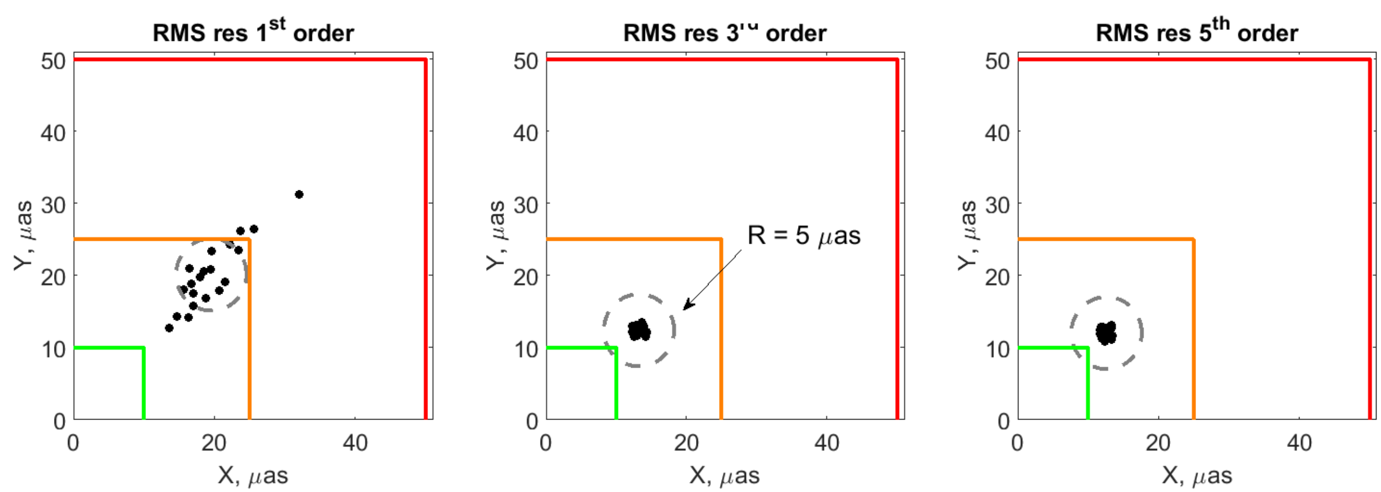






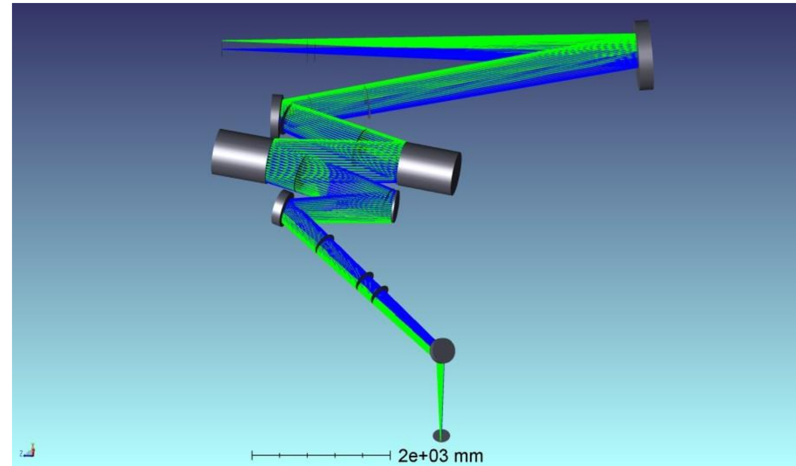


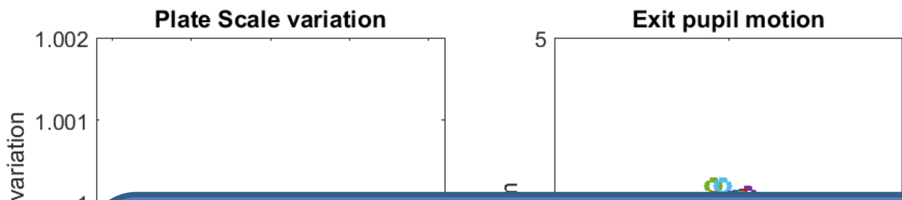
- DMs nominal sag from prescription



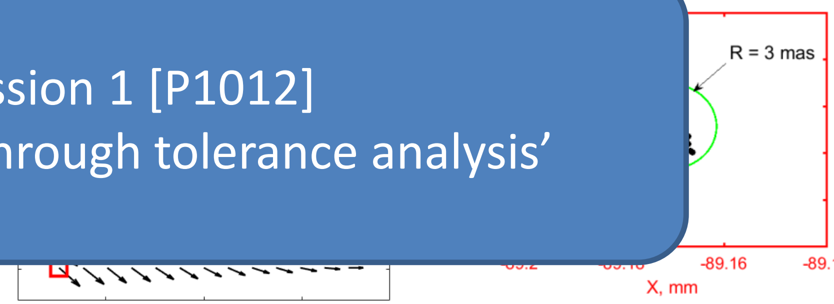
MAORY Tolerances

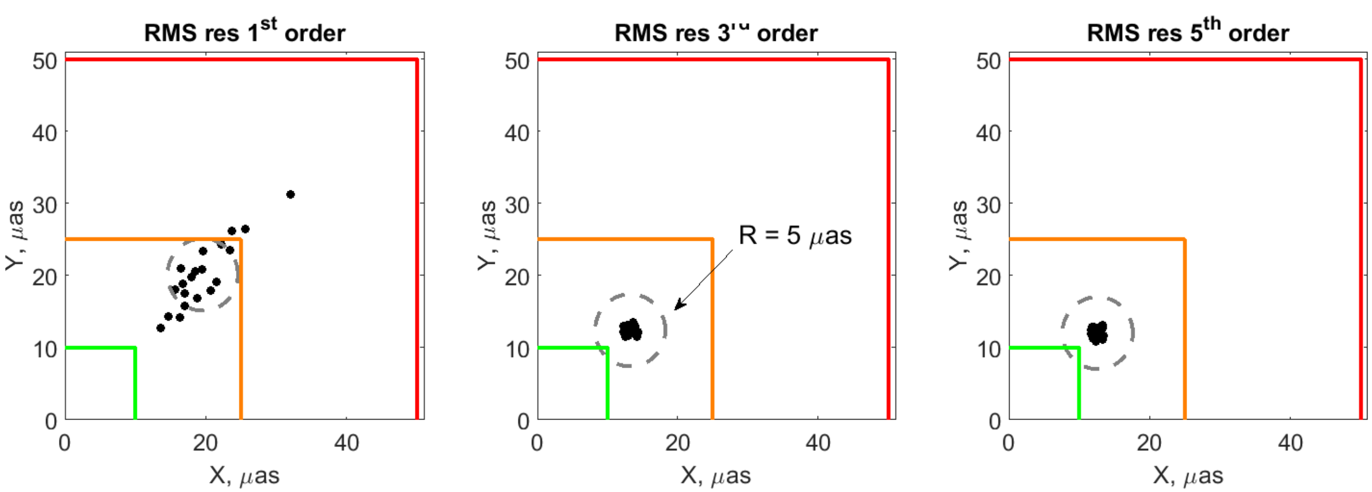
-50 µm < dx, dy, dz < +50 µm + ΔBench(dT/h = 1°C)
-0.001° < θx, θy < +0.001°





Mauro Patti’s Poster session 1 [P1012]
‘Exploring MAORY performances through tolerance analysis’

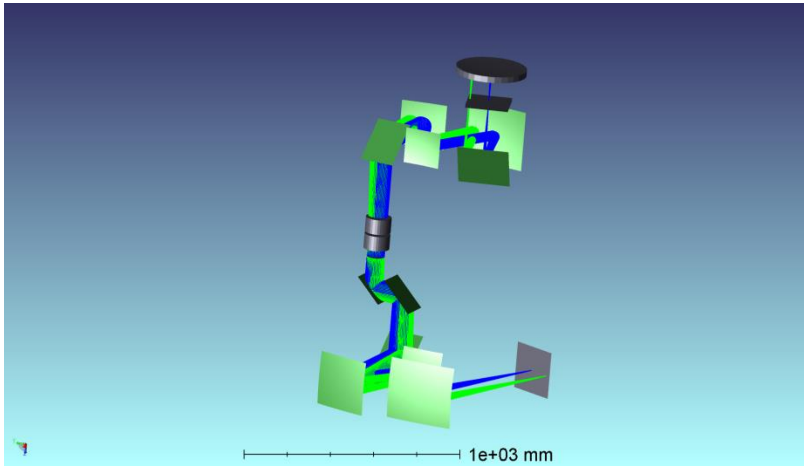


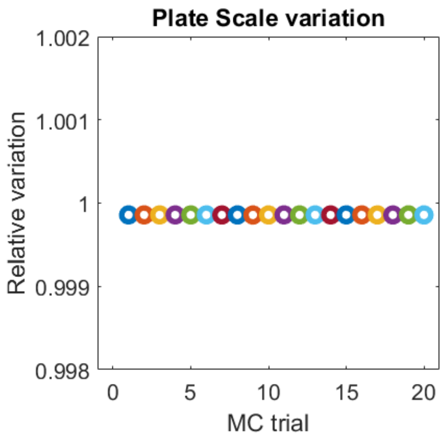


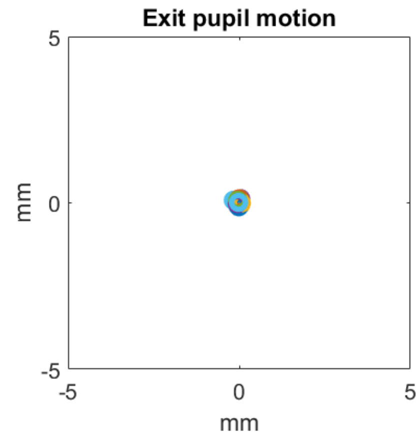
MICADO Tolerances

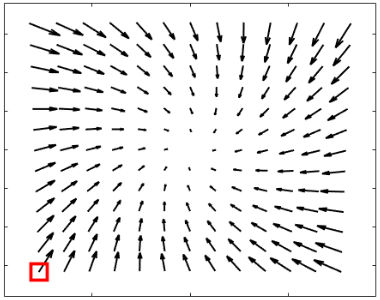
-0.5 µm < dx, dy, dz < +0.5 µm

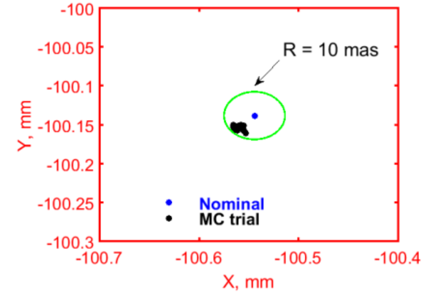
-0.001° < θx, θy < +0.001° (Scheiding, 2010)

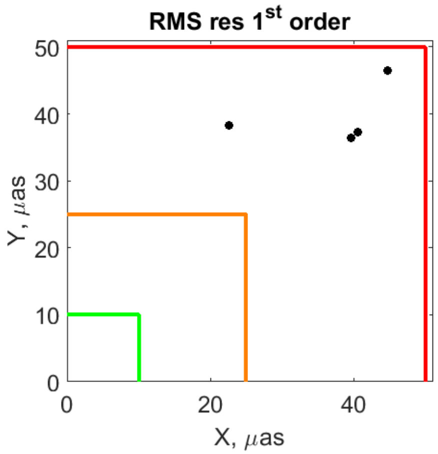


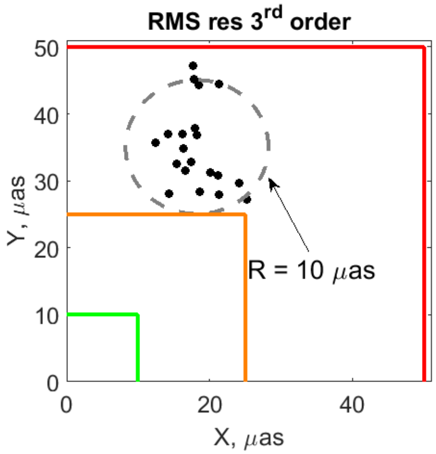


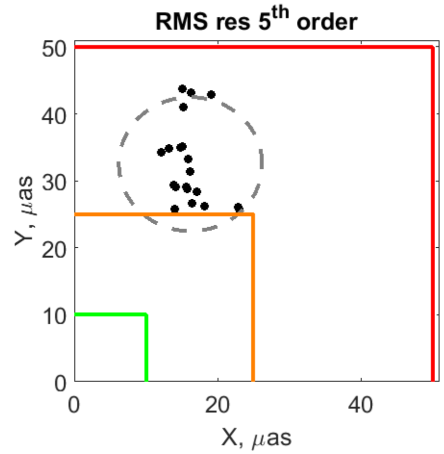








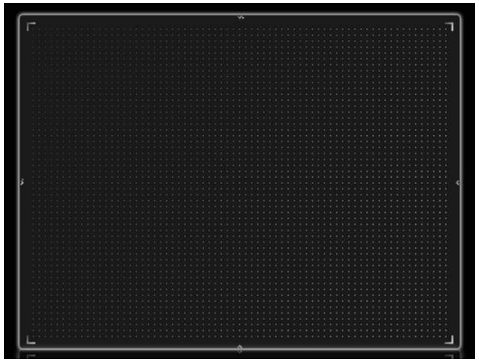


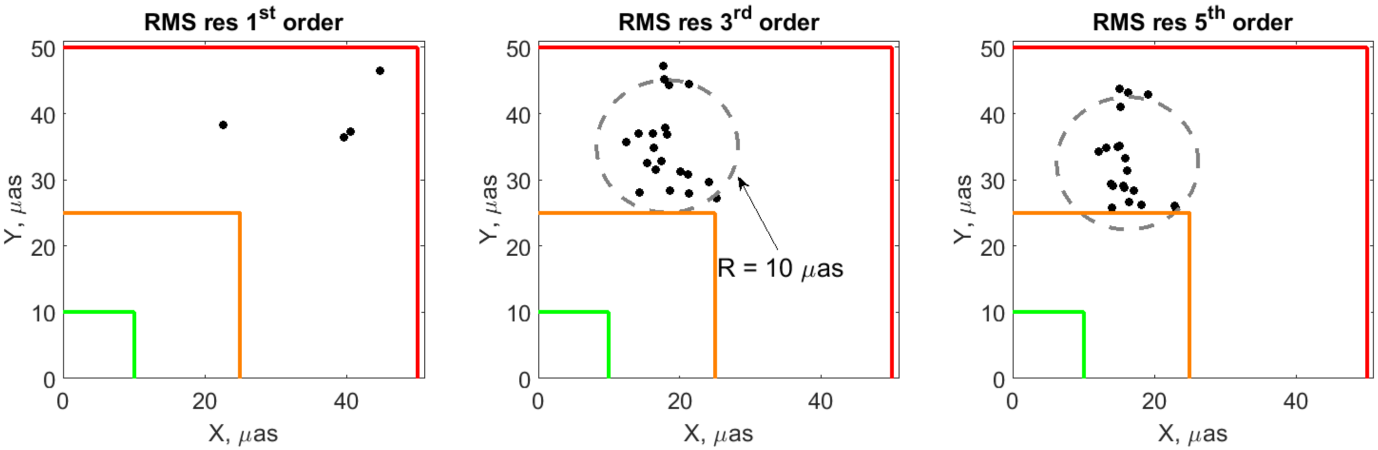


MICADO Tolerances

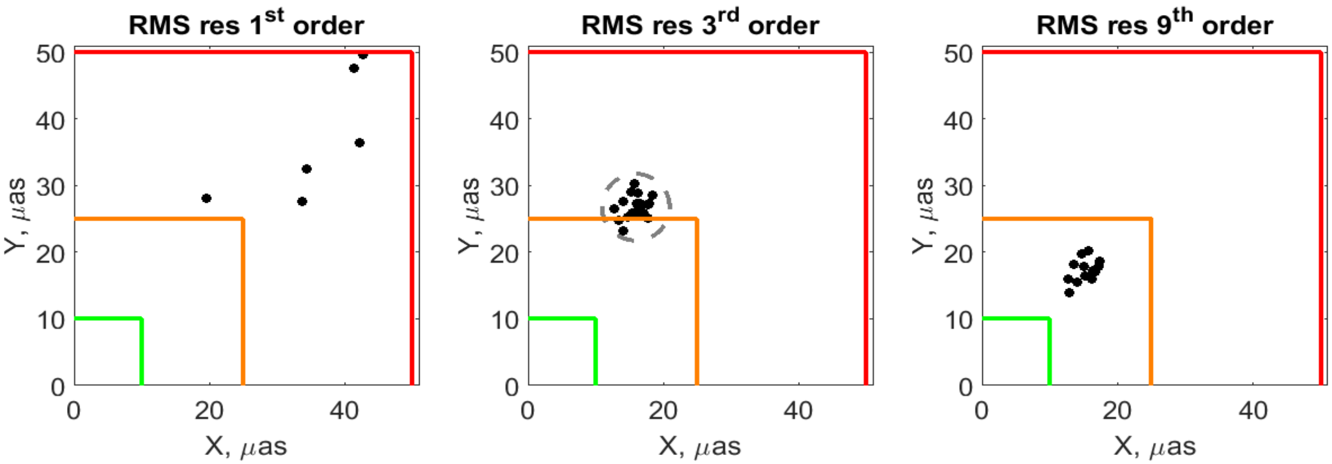
MICADO and MAORY optical distortions

Calibrated with astrometric calibration masks





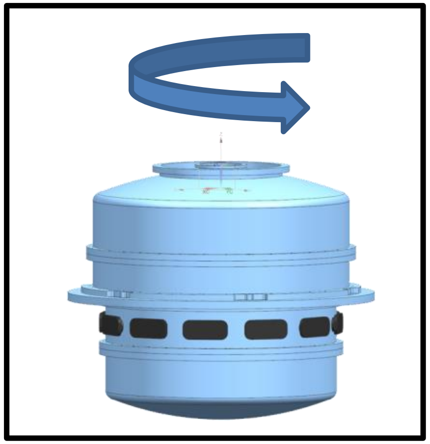
144 points

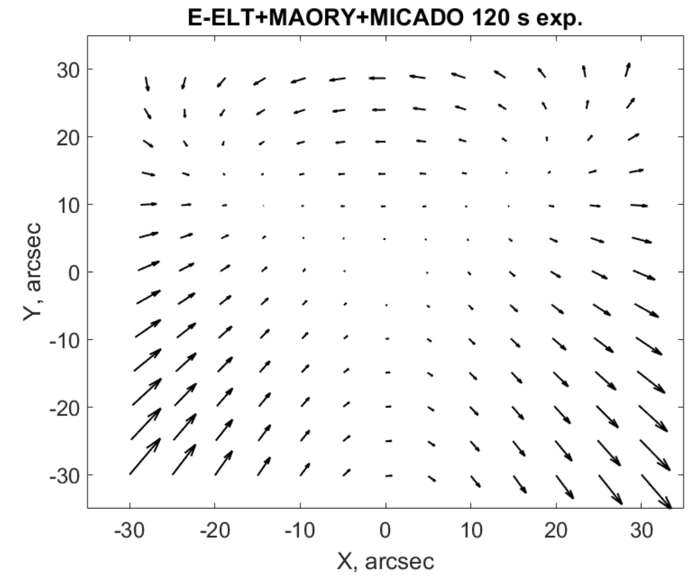


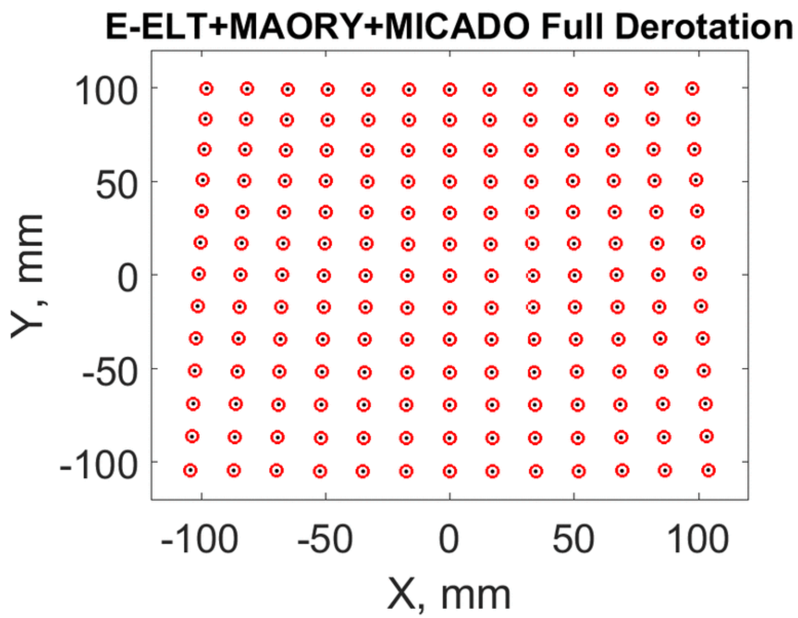
900 points

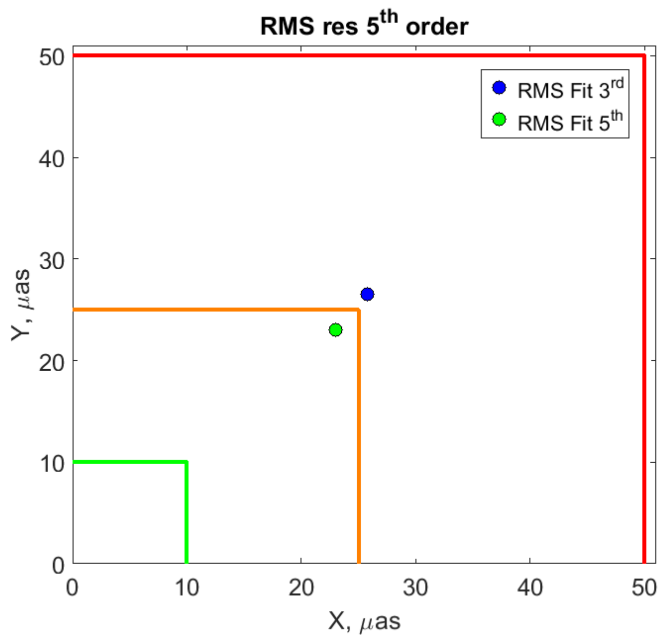
Distortion(Derotation)

Derotation MAORY-MICADO
Max speed 79”/s
Max exposure 120 s
Diff. Derotation <= 2.6°



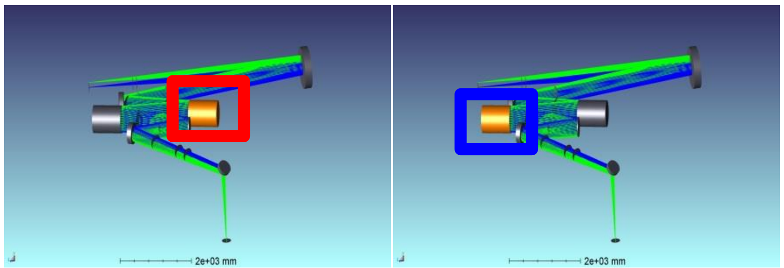




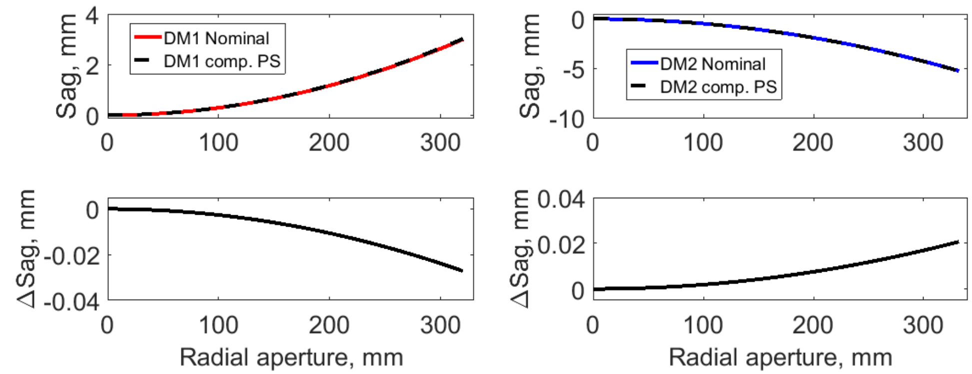


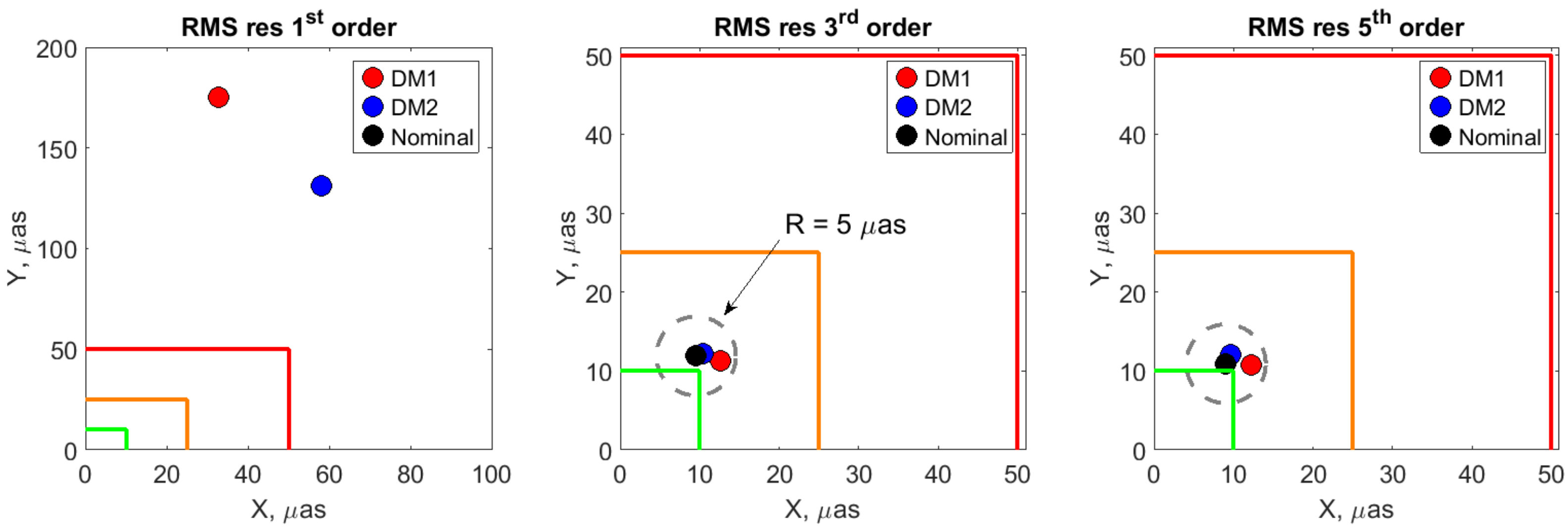
E-ELT PS compensation with MAORY DMs

M2 Δz = 1 mm -> **ΔPlate Scale = 1%**
Restore PS with MAORY DMs
Guiding windows on MICADO detector



Stroke required 20-30 µm

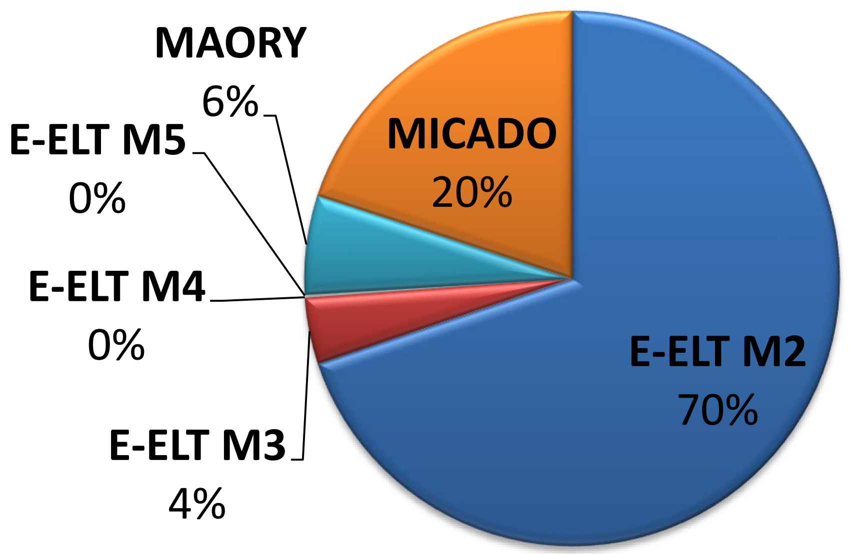




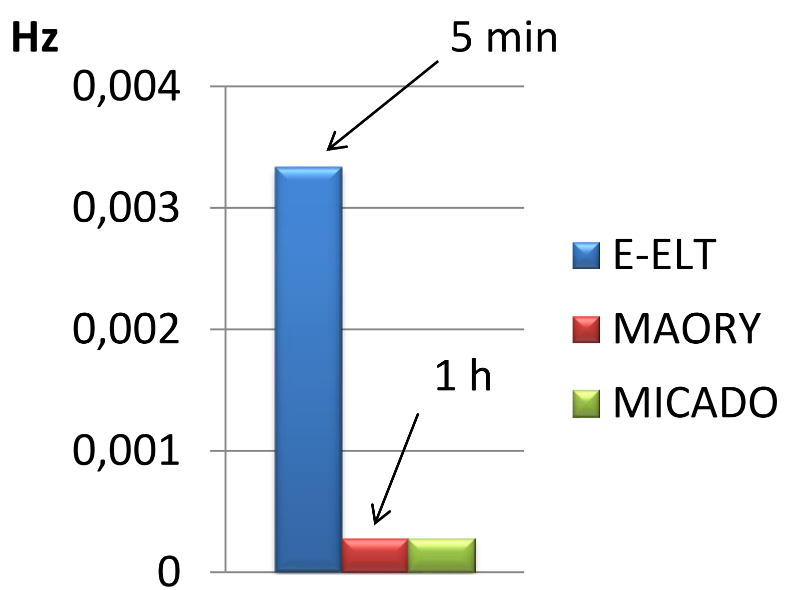
Astrometric Error Budget summary

- Mirror misalignment/positioning errors
- Thermo-mechanical drifts
- Dynamical effect (LOO)

Distortion intrinsic+tolerances



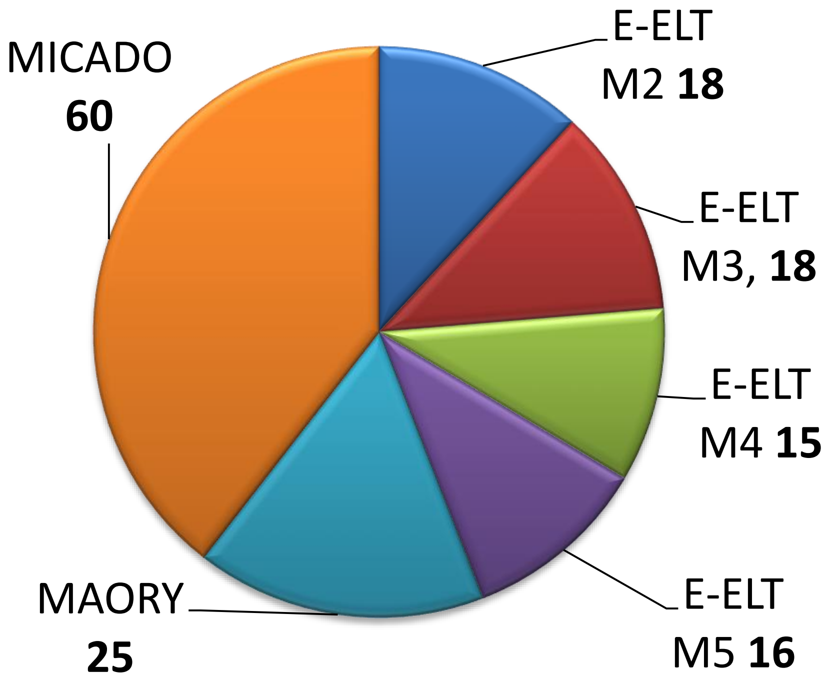
Timescales



NIRSPEC TMA ≈ 0.4 h (Yi, 2015)

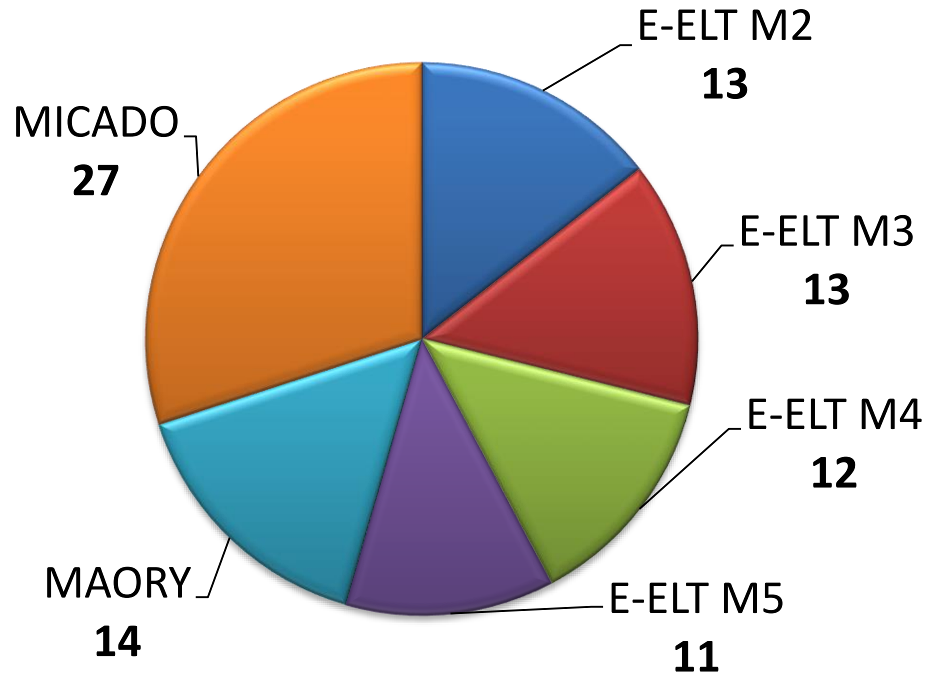
Astrometric Error Budget summary

RMS residuals post 1st fit



[µas]

RMS residuals post 3rd fit



[µas]

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV
- M2 PS drift 35mas/30"/5min, optimum for MAORY-MICADO 0.5-1mas/30"

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV
- M2 PS drift 35mas/30”/5min, optimum for MAORY-MICADO 0.5-1mas/30”
- E-ELT distortion well fitted with 3rd order polynomial

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV
- M2 PS drift 35mas/30”/5min, optimum for MAORY-MICADO 0.5-1mas/30”
- E-ELT distortion well fitted with 3rd order polynomial
- E-ELT M5 induces field rotation at MICADO PSF scale

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV
- M2 PS drift 35mas/30”/5min, optimum for MAORY-MICADO 0.5-1mas/30”
- E-ELT distortion well fitted with 3rd order polynomial
- E-ELT M5 induces field rotation at MICADO PSF scale
- MAORY and MICADO higher order distortions, but slower variation

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV
- M2 PS drift 35mas/30”/5min, optimum for MAORY-MICADO 0.5-1mas/30”
- E-ELT distortion well fitted with 3rd order polynomial
- E-ELT M5 induces field rotation at MICADO PSF scale
- MAORY and MICADO higher order distortions, but slower variation
- Higher distortions in MAORY & MICADO calibration -> astrometric masks

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV
- M2 PS drift 35mas/30”/5min, optimum for MAORY-MICADO 0.5-1mas/30”
- E-ELT distortion well fitted with 3rd order polynomial
- E-ELT M5 induces field rotation at MICADO PSF scale
- MAORY and MICADO higher order distortions, but slower variation
- Higher distortions in MAORY & MICADO calibration -> astrometric masks

Possible strategies:

- Smaller FoV

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV
- M2 PS drift 35mas/30”/5min, optimum for MAORY-MICADO 0.5-1mas/30”
- E-ELT distortion well fitted with 3rd order polynomial
- E-ELT M5 induces field rotation at MICADO PSF scale
- MAORY and MICADO higher order distortions, but slower variation
- Higher distortions in MAORY & MICADO calibration -> astrometric masks

Possible strategies:

- Smaller FoV
- Plate Scale control beyond E-ELT collimation control

Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV
- M2 PS drift 35mas/30”/5min, optimum for MAORY-MICADO 0.5-1mas/30”
- E-ELT distortion well fitted with 3rd order polynomial
- E-ELT M5 induces field rotation at MICADO PSF scale
- MAORY and MICADO higher order distortions, but slower variation
- Higher distortions in MAORY & MICADO calibration -> astrometric masks

Possible strategies:

- Smaller FoV
- Plate Scale control beyond E-ELT collimation control
- Integrate faster, penalty -> higher RON

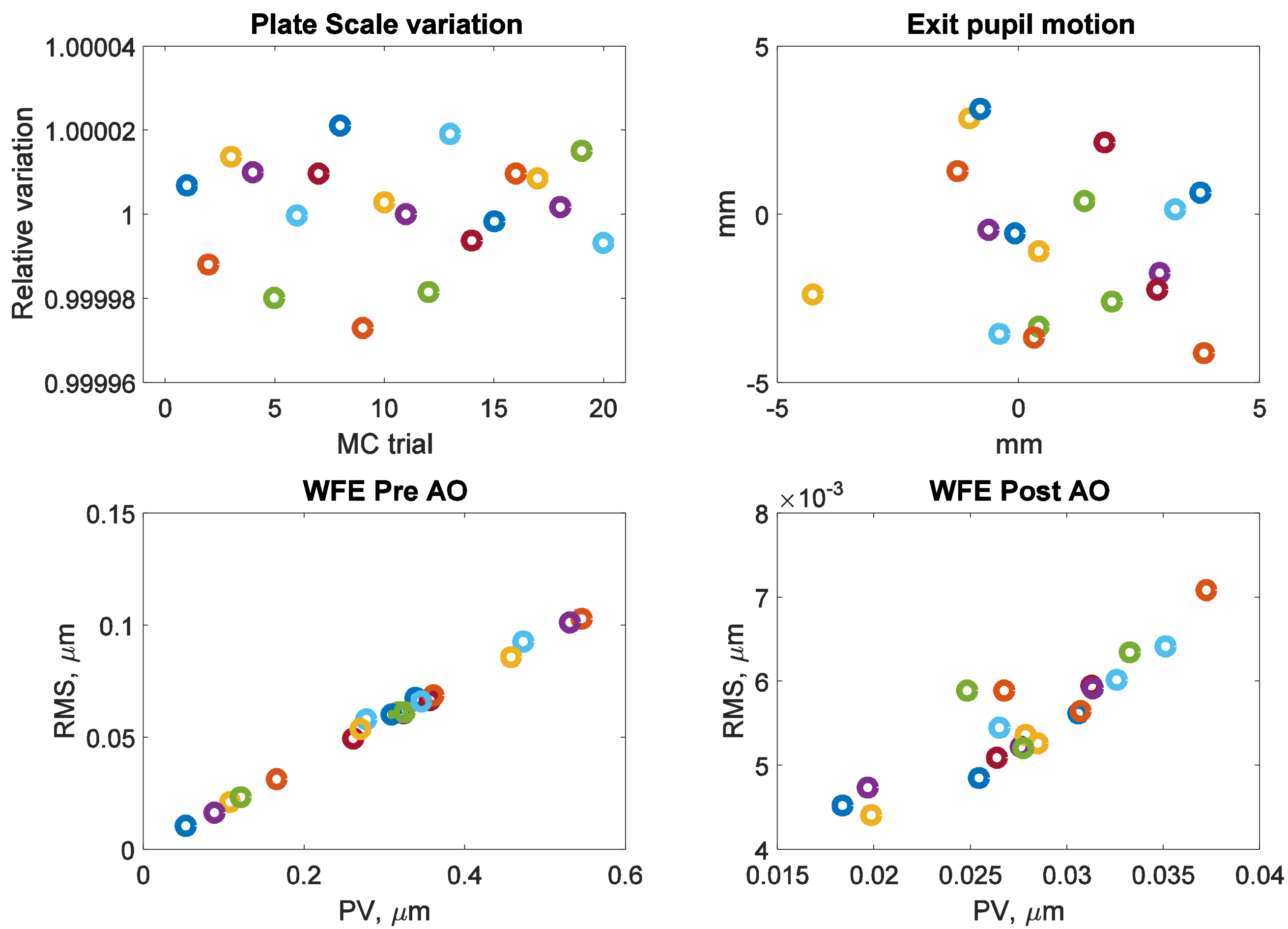
Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
- At 2 min timescales (NB BG limited) many effects smear out the PSF at the edge of FoV
- M2 PS drift 35mas/30”/5min, optimum for MAORY-MICADO 0.5-1mas/30”
- E-ELT distortion well fitted with 3rd order polynomial
- E-ELT M5 induces field rotation at MICADO PSF scale
- MAORY and MICADO higher order distortions, but slower variation
- Higher distortions in MAORY & MICADO calibration -> astrometric masks

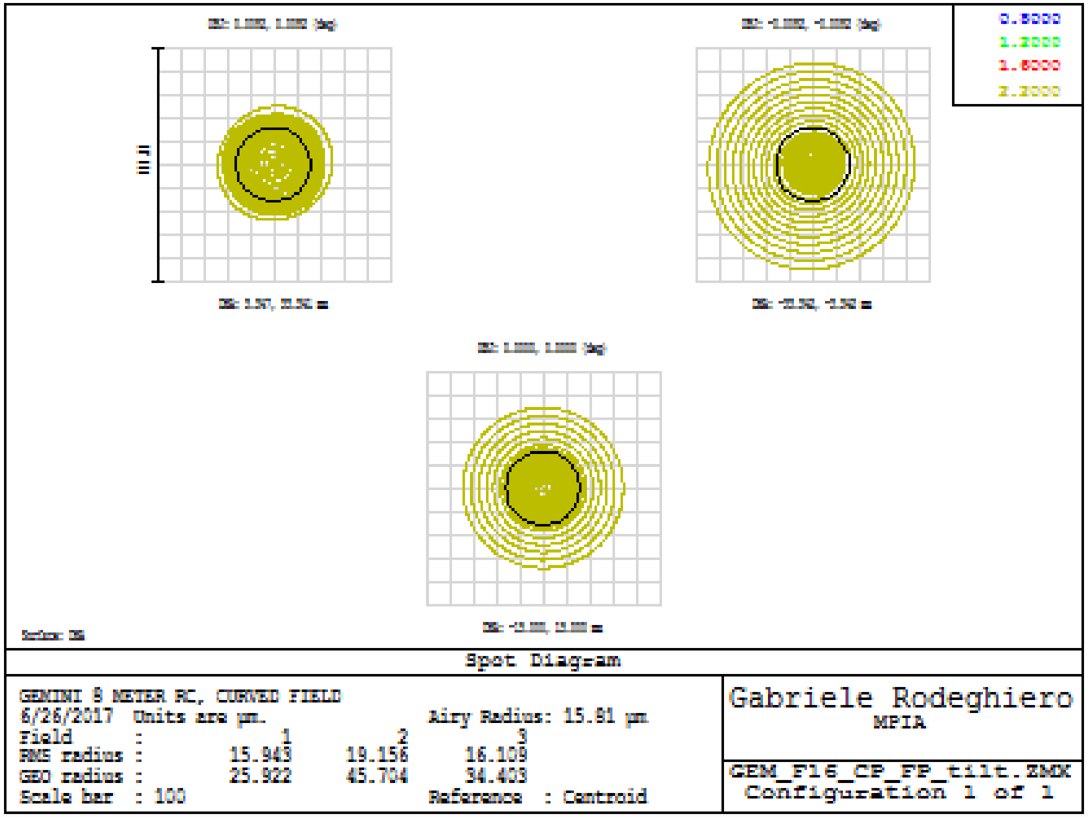
Possible strategies:

- Smaller FoV
- Plate Scale control beyond E-ELT collimation control
- Integrate faster, penalty -> higher RON
- Try to fit the distortion drifts over exposure timescale (PS, FR drifts)

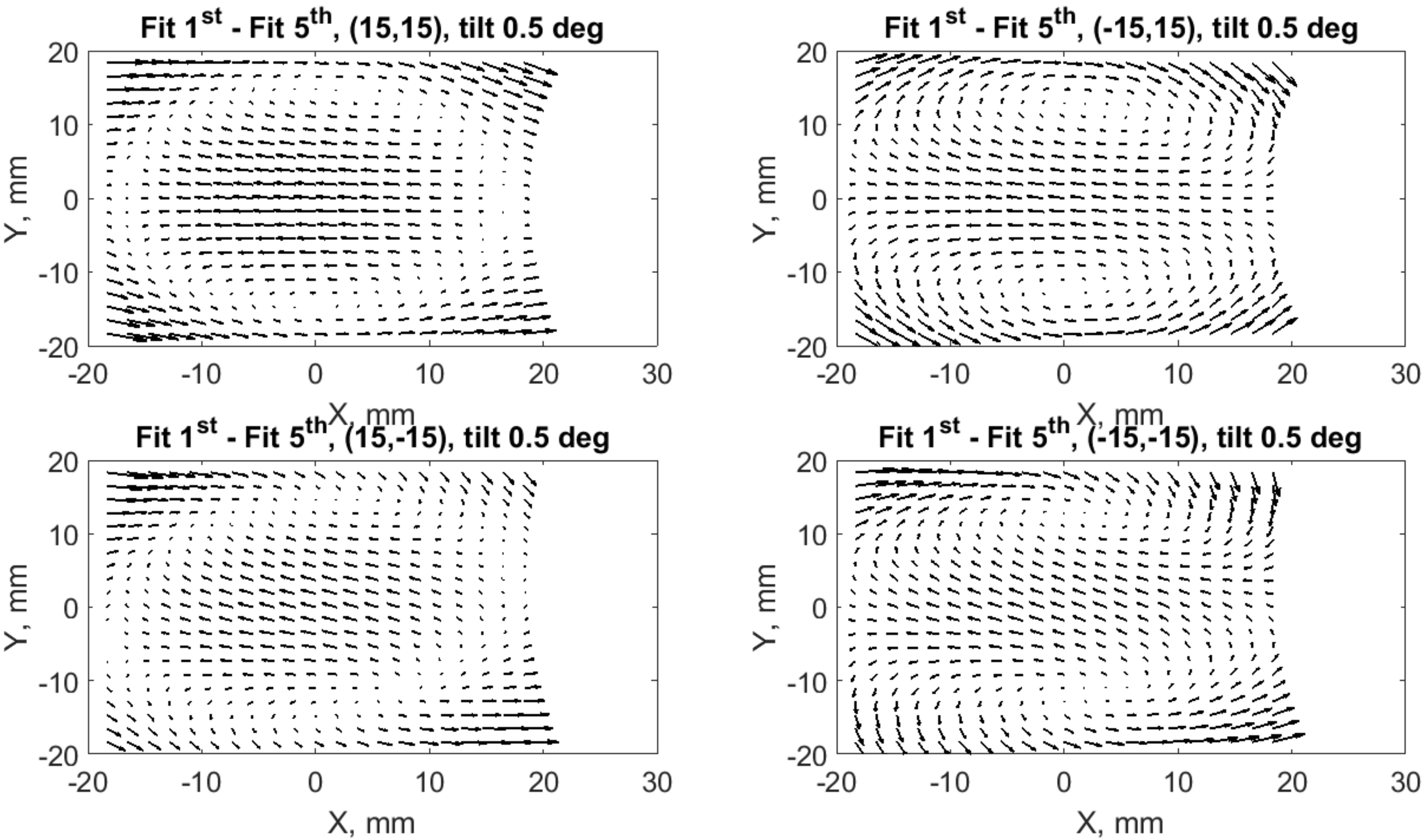
Backup slides



Backup slides



Backup slides



Backup slides