Towards an overall astrometric error budget with MICADO-MCAO


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

\[ \sigma = \frac{FWHM}{SNR} \]

- VLT / 5
- 25 x VLT
- \( \sigma_{ELTs} \approx \sigma_{8m\ class}/5 \)

Telescopes 5 times bigger smaller \( FWHM \) & higher \( SNR \) BUT stability issues
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 stabilization
- F#17.7, M1 diameter 38.5 m
E-ELT+MAORY+MICADO

MAORY
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E-ELT
- MCAO module
- 1-2 Post-focal DMs
- DM@ 12.7 & 5 km
- F#17.7
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E-ELT
- Camera & spectrometer
- 2 TMAs, only fixed mirrors
- Cryogenic, gravity invariant
- FoV 53”, pixel scale 1.5-4.5 mas

MICADO
-
MC tolerances approach

- OpticStudio (Zemax) ZOS-API using Matlab

Caveat
Preliminary data/assumed values

Run $n$
MonteCarlo

M2 shift → WFE in Zernike terms → M4 AO & M5 tip tilt correction

Distortion Polynomial fit → Focal plane Distortion

Astrometric Error Residual

E-ELT → MAORY → MICADO
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

\[-0.1 \text{ mm} < dx, \ dy < +0.1 \text{ mm} \rightarrow dz = 0\]

\[-0.01^\circ < \theta x, \ \theta y < +0.01^\circ\]
M2 Low Order Optimization

dy, dz = 0 $\rightarrow$ 100 $\mu$m
$\theta = 0 \rightarrow 0.01^\circ$ \hspace{1em} (Mueller, 2014)
M2 shape aberrations

RMS = 506 nm astigmatism on M2  (Mueller, 2014)

M1 phasing compensation of M2 deformation

At exit pupil

Induced distortion

RMS residuals
M3 Tolerances

-0.1 mm < dx, dy, dz < +0.1 mm
-0.01° < θx, θy < +0.01°  (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 1\textsuperscript{st} & 3\textsuperscript{rd} order polynomial fit the astrometry residuals are 10-20 µas
- 5\textsuperscript{th} order polynomial fit -> no significant improvement

- 1\textsuperscript{st} 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

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

<table>
<thead>
<tr>
<th>Tilt</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
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<td>0.01°</td>
<td>-</td>
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<td>$\theta_y$</td>
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<td>-</td>
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<tr>
<td>$\theta_z$</td>
<td>0.01°</td>
<td>-</td>
<td>10”</td>
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<table>
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<tr>
<th>Field</th>
<th>H, mas</th>
<th>K, mas</th>
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<tr>
<td>On axis</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Off axis</td>
<td>10</td>
<td>13</td>
</tr>
</tbody>
</table>
MAORY Tolerances

-50 \mu m < dx, dy, dz < +50 \mu m + \Delta \text{Bench}(dT/h = 1^\circ \text{C})
-0.001^\circ < \theta_x, \theta_y < +0.001^\circ

- 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’

RMS res 1st order
RMS res 3rd order
RMS res 5th order
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

RMS res 1\textsuperscript{st} order

RMS res 3\textsuperscript{rd} order

RMS res 5\textsuperscript{th} order

RMS res 1\textsuperscript{st} order

RMS res 3\textsuperscript{rd} order

RMS res 9\textsuperscript{th} order

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 $\Delta z = 1 \text{ mm} \rightarrow \Delta \text{Plate Scale} = 1\%$

Restore PS with MAORY DMs
Guiding windows on MICADO detector

Stroke required 20-30 $\mu\text{m}$
Astrometric Error Budget summary

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

Distortion intrinsic+tolerances

- E-ELT M2: 70%
- E-ELT M3: 4%
- E-ELT M4: 0%
- E-ELT M5: 0%
- MAORY: 6%
- MICADO: 20%

Timescales

- 5 min
- 1 h

NIRSPEC TMA ≈ 0.4 h (Yi, 2015)
Astrometric Error Budget summary

RMS residuals post 1\textsuperscript{st} fit

- MICADO: 60 [\mu\text{as}]
- E-ELT M2: 18 [\mu\text{as}]
- E-ELT M3: 18 [\mu\text{as}]
- E-ELT M4: 15 [\mu\text{as}]
- E-ELT M5: 16 [\mu\text{as}]
- MAORY: 25 [\mu\text{as}]

RMS residuals post 3\textsuperscript{rd} fit

- MICADO: 27 [\mu\text{as}]
- E-ELT M2: 13 [\mu\text{as}]
- E-ELT M3: 13 [\mu\text{as}]
- E-ELT M4: 12 [\mu\text{as}]
- E-ELT M5: 11 [\mu\text{as}]
- MAORY: 14 [\mu\text{as}]
Conclusions & future perspectives

- E-ELT dominant distortion -> PS change, limit on exposure time
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- Smaller FoV
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- Integrate faster, penalty -> higher RON
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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

Plate Scale variation

Exit pupil motion

WFE Pre AO

WFE Post AO
Backup slides
Backup slides
Backup slides

Distortion @ Gemini FP (15,15), tilt 0.5 deg

Points
Distortion res 5th