MAORY design trade-off study: tomography dimensioning

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Multi-conjugate Adaptive Optics RelaY for the ELT

MAORY serves MICADO + future second port INS (TBD)
Outline: phase B design trade-off

1- Analysis of dimensioning parameters constrained by tomographic and generalized fitting error

- Number of post-focal DMs conjugated in altitude
- DM pitch
- DM altitudes
- LGS asterism angle
- Number of LGS
- LGS and NGS asterism geometry - not shown in this talk

under some constraints

- Seeing
- Cn2 profile
- Zenith distance
- Telescope phase 1 / phase 2
  - Number of LGSs: 4/6
  - M1 central obstruction: 28%/57%
Driver: MAORY main specifications

- **Performance in best conditions**
  - Q1 seeing (0.234 m) and wind, as close to zenith as possible
  - Over 20” FoV
  - SR > 50% @ 2.2 microns (goal 60%)
  - Sky coverage requirement not applicable

- **Performance in median conditions**
  - Median seeing (0.157 m) and wind, as close to zenith as possible
  - Over 1’ FoV
  - SR > 30% @ 2.2 microns (goal 50% @ 2 microns)

- **Performance in sub optimal conditions**
  - Q3 seeing (0.139 m) and wind, zenith distance 30 degrees
  - Over 2’ FoV
  - SR > 15% @ 2.2 microns (goal 30%)

- **SR uniformity** < 10% absolute PTV across FoV of interest
- **Sky coverage** > 50%
OCTOPUS® end-to-end simulation

Simulated MCAO WFE terms
- Generalized fitting
- Spatial aliasing
- Temporal error
- LGS WFS noise
- NGS WFS noise
- Tomographic error

Command computation:
- Tomographic reconstruction to estimate the multi layer turbulent phase: FRIM3D/POLC with perfect priors on Cn² profile
- Projection of the estimated 3D phase onto the DMs space. The projection is optimized on a specific FoV

No other error budget term
Typical simulated FoV

- MICADO small field 20”x20”
- MICADO large field 53”x53”
Cn² profiles

3 Cn² profiles

normalized Cn2

Altitude [m]

+ other profiles measured by stereo scidar
- 2 post-focal DMs: performance flat for pitch < 1.5 m
- 1 post-focal DM: performance flat for pitch < 2 m
- Strong impact from Cn2 profile

\[ r_0 = 0.129 \, \text{m}, \, Z = 30^\circ \]
Benefit 2 vs. 1 post-focal DM(s)

- 2 post-focal DMs desirable to increase sky coverage
- 2 post-focal DMs provide performance improvement of up to 25% in the science field and 100% in the technical field in K band, 250% in J band

- 2 post-focal DMs desirable to increase sky coverage
Benefit 2 vs. 1 post-focal DM(s)

- 2 post-focal DMs improve tolerance to Cn2 profile variation
E-ELT phase 1 / phase 2 – K band

- M1 doughnut impact on Sr is marginal. How about NGS sky coverage?
- **Significant impact 6 LGSs → 4 LGSs**
- E-ELT phase 1: limited by tomographic error → DM pitch irrelevant
- 6 LGSs enable benefit from 2 post-focal DMs and finer pitch

**K band: 2.2 µm**

\[ r_0 = 0.129 \text{ m}, \ Z=30^\circ \]

\[ C_n^2: \text{Profile 1} \]

**Photon noise** \( \sigma^2 \times 3.8 \text{ long axis} \)
M1 doughnut impact on Sr is not significant. How about NGS sky coverage?

Dramatic impact 6 LGSs $\rightarrow$ 4 LGSs

Lower wavelength performance pushes for:

- **6 LGSs**
- 2 post-focal DMs
- finer DM pitch

$K$ band: $2.2 \, \mu m$

$r_0=0.129 \, m$, $Z=30^\circ$

$C_n^2$: Profile 1

Photon noise $\sigma^2$ $\times 3.8$ long axis
1 post-focal DM: conjugation **altitude** matters and should be > 14 km

- The conjugation altitude should be higher to cope with larger airmass cases

- **K band:** 2.2 μm
  \[ r_0 = 0.129 \text{ m}, \ Z = 30^\circ \]
  \[ C_n^2: \text{Profile 1} \]

- MAORY - 1 alt DM - no elong - pitch 1m

- 1 post-focal DM: conjugation **altitude** matters and should be > 14 km
- The conjugation altitude should be higher to cope with larger airmass cases
Results confirmed by $C_n^2$ sensitivity study
- Performance insensitive to DM1 altitude
- DM2 optimal altitude naturally increases with airmass
- 16 km conjugation is a good trade-off
- 16 km is also close to optimal for a single post-focal DM $\rightarrow$ Upgradability
Sensitivity $C_n^2$ profile: DM2 altitude

- DM2 altitude should obviously be increased at larger airmass
- Dependency on profile is not significant
- Again 16 km conjugation looks like a good compromise
Sensitivity $Cn^2$ profile: DM1 altitude

- DM1 altitude has a weak influence
- No clear dependency on Cn2 profile
- The opto-mechanical design should drive the DM1 altitude
Tomography reconstruction maximizes performance in full field here

Closer LGSs improve Sr on axis, decrease uniformity across the MICADO field and decrease the Sr in the technical field

Trade-off between 45” and 1’ radii → other FoV optimization to check
Tomography reconstruction maximizes performance in 3 different FoVs with NGS @ 70” off axis

Maximum and average Sr in MICADO field highest for LGS @ 45” off axis

Average performance in 2’ FoV highest for LGS @ 1’ off axis

Baseline: 45” radius
Ultimate performance in 20” square

- Best performance on axis (LTAO with on axis NGS) is achieved with 20” radius @ Z=60
- NGS cannot be closer than 30” radius without vignetting the science FoV
- Confirmation that a fixed 45” radius is almost optimal for MICADO at any airmass for both small field and wide field: one single asterism configuration → less complexity
Conclusions on design trade-off

- 2 post-focal DMs (baseline: 1) are desirable in order to enhance:
  - Performance in the technical field → sky coverage and robustness (acquisition)
  - Performance in the blue for NGS sky coverage and MICADO performance
  - Robustness to Cn2 profile variation and zenith distance

- DM pitch between 2m and 1.5m → better for worse seeing and with 2 DMs

- Post-focal DMs altitude: 4-6 and 16 km to be robust to larger airmass and accommodate 2 post-focal DMs later

- LGS asterism angle: fixed @ 45” radius + optimization of tomography projection depending on FoV of interest

- E-ELT phase 1 / phase 2:
  - M1 doughnut main impact on sky coverage and PSF shape: TBC
  - 6 LGSs are highly desirable
Thank you for your attention!