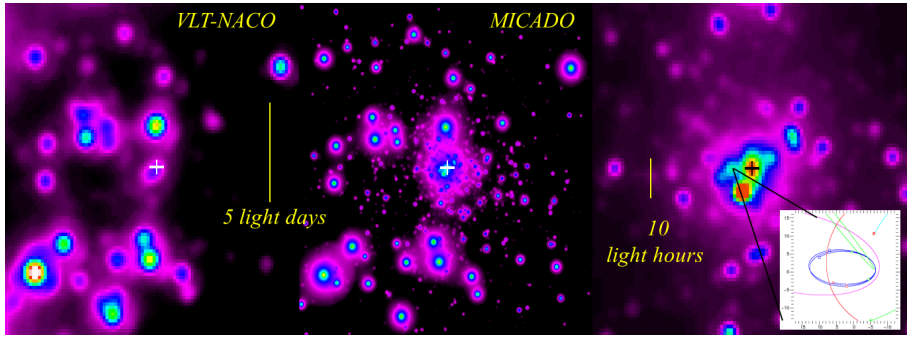
Preliminary design of the MICADO Calibration Unit

G. Rodeghiero
on the behalf of the MICADO MPIA Team

Overview

- MICADO instrument
- MICADO Calibration Unit
- Relative astrometry with ELTs
- Distortion sensitivity analysis
- Strategies for calibration



MICADO

MPE

LMU USM

NOVA

Institut für Astrophysik Göttingen

cnrs

INAF

ESO

Key Capabilities

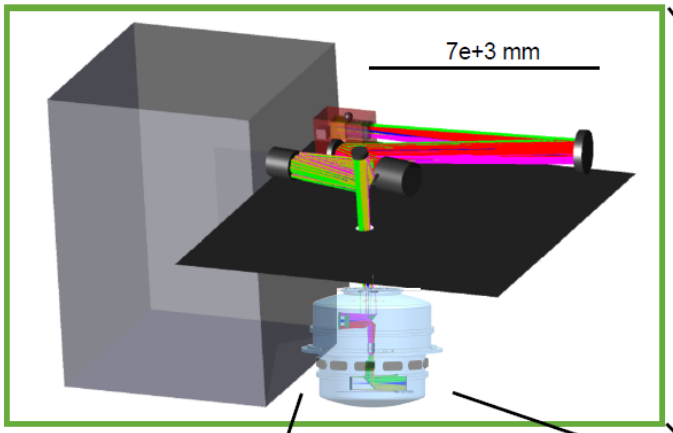
- ❑ Imaging
  - 0.8-2.4µm with >30 broad/narrow filters
  - 1.5 mas for 19” FoV & 4.5 mas pixels at 53” FoV
  - Similar sensitivity to JWST, and 6× better resolution
- ❑ **Astrometric imaging**
  - 10-50µas precision in the field
  - 10µas/yr = 5km/s at 100kpc after only a few years
- ❑ Spectroscopy
  - ideal for compact sources
  - fixed configuration for 0.8-1.45µm & 1.21-2.4µm
  - R ~ 20000 for point sources (R ~ 10000 integrated across slit)
- ❑ High Contrast imaging
  - focal & pupil plane coronagraphs
  - angular differential imaging
  - small inner working angle
- ❑ Time Resolved Astronomy
  - windowing for frame rates up to 10Hz

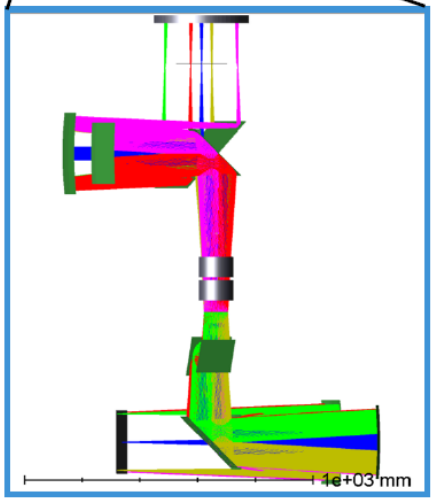
Science Cases

❑ Galaxy evolution @ high z	• Galaxy evolution & formation at high redshift • Continuum and emission line mapping • Resolve star forming regions in galaxy clusters
❑ Black holes in galaxy centres	• Exploring strong gravity regime, stellar motion • AGN feedback
❑ Resolved stellar populations	• Internal kinematics of GC and dwarf galaxies • Resolve population in Virgo clusters
❑ Coronagrpahy and exoplanets	• 10-20AU orbits around young stars at distance of 100-150 pc • Circumstellar disks
❑ Solar System	• FoV matching size of Venus, Jupiter, Saturn • TNO, KBO
❑ Time Resolved Astronomy	• Neutron stars, magnetars

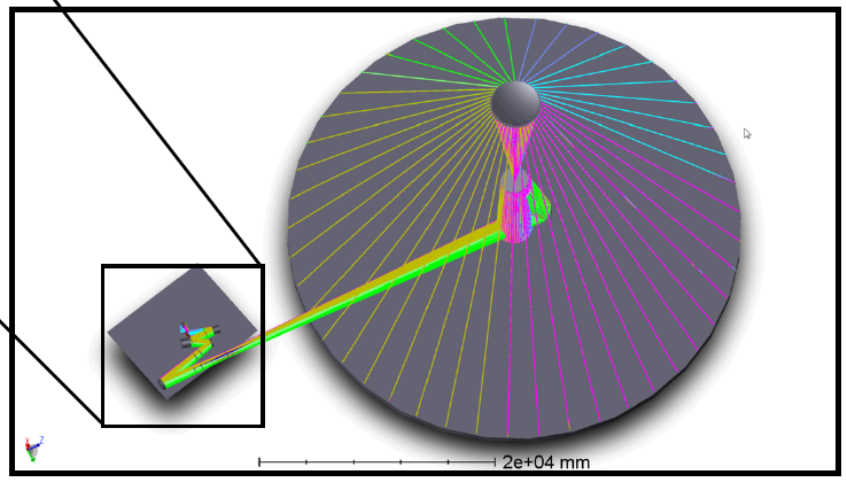
ELT+MAORY+MICADO

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





ELT



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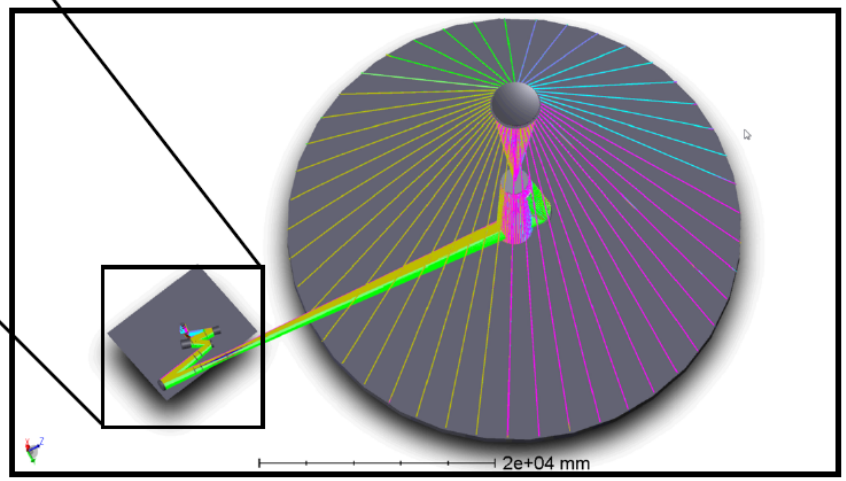
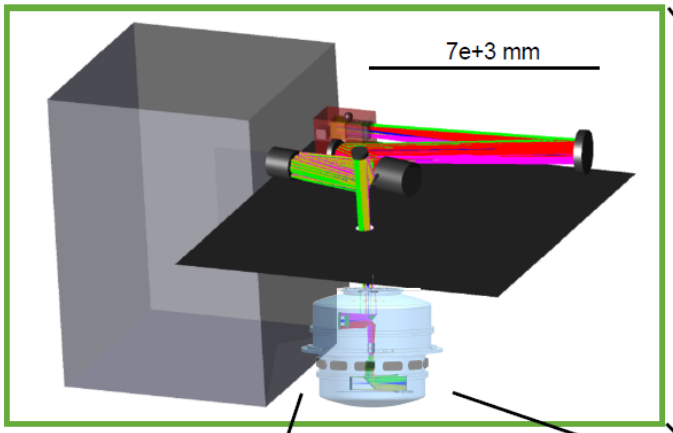
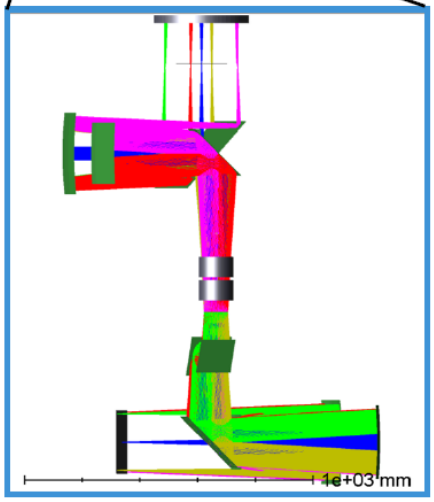


MAORY

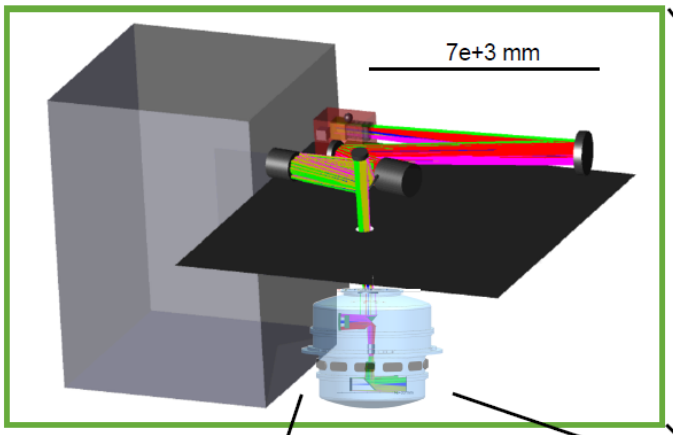




- MCAO module
- 1-2 Post-focal DMs
- DM@ 12.7 & 5 km
- F#17.7

ELT+MAORY+MICADO

MAORY



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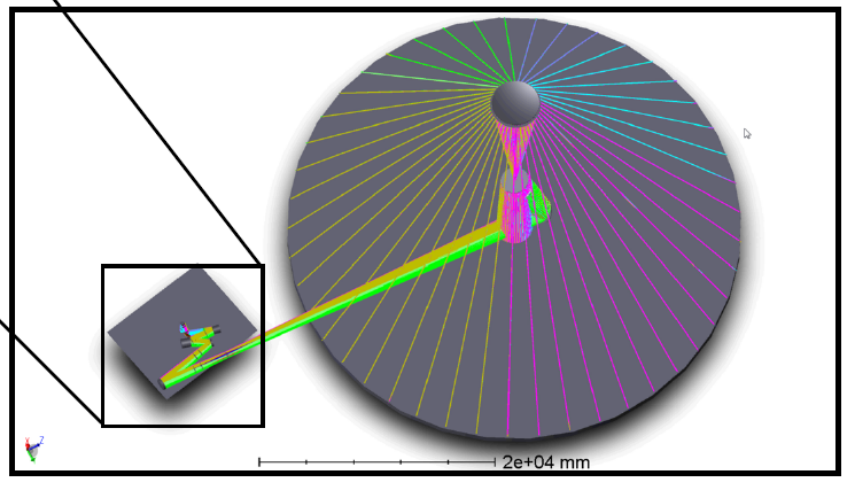
ELT



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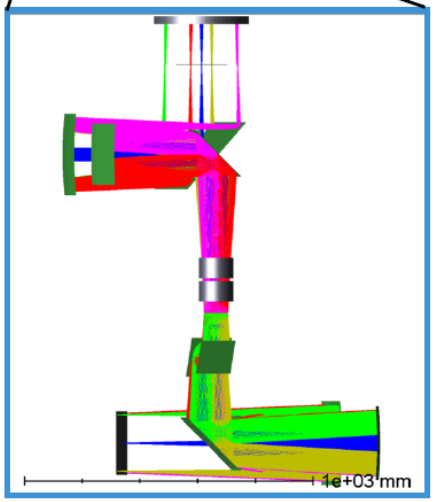
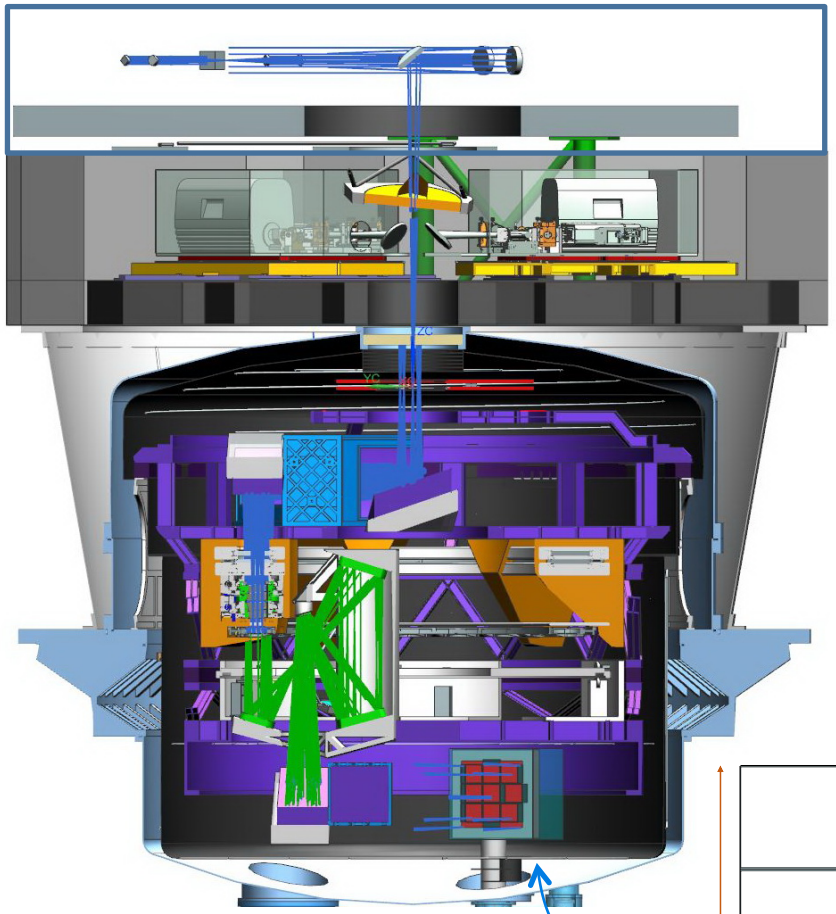


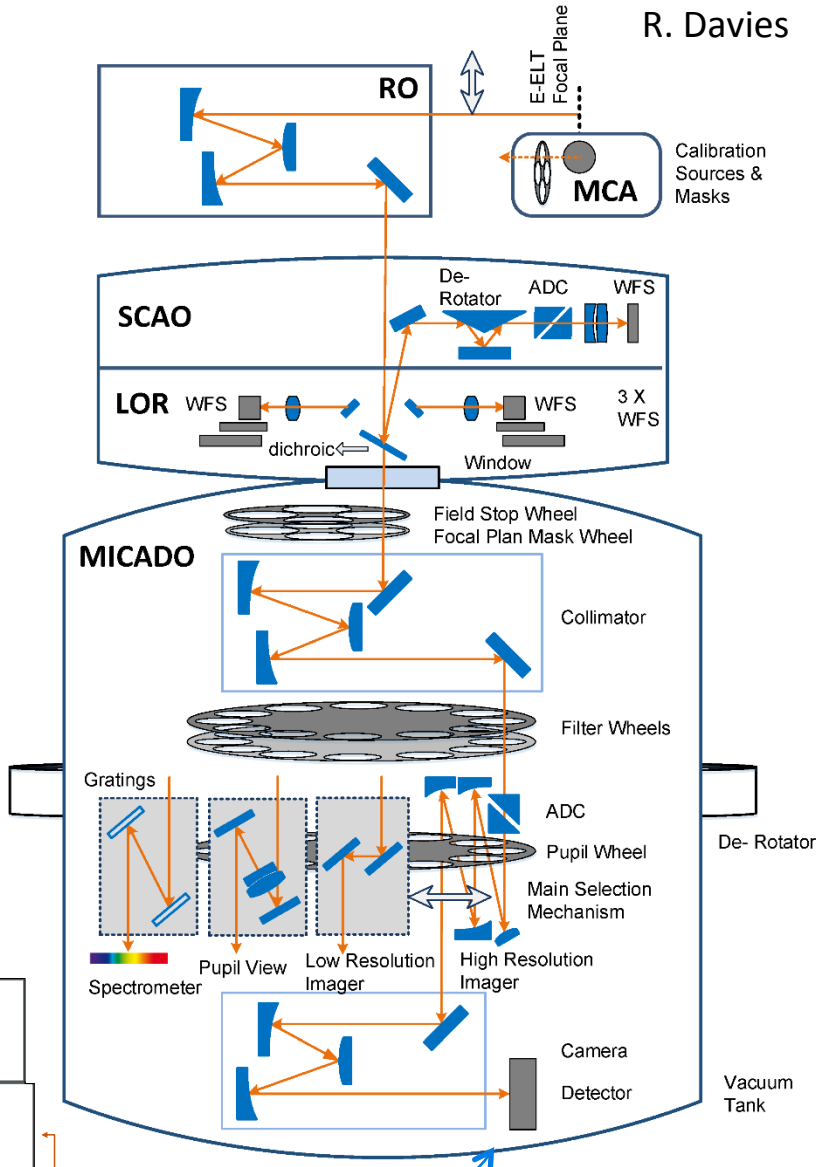
MICADO

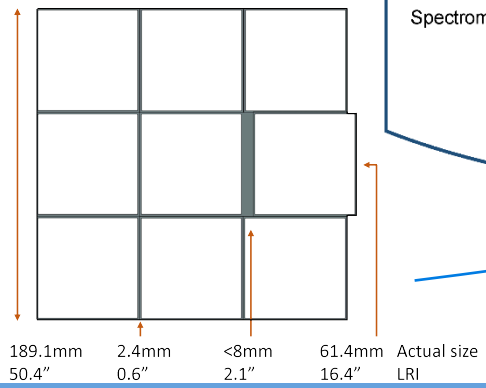
- Camera & spectrograph
- 2 TMAs, only fixed mirrors
- Cryogenic, gravity invariant
- FoV 53”, pixel scale 1.5-4.5 mas

MICADO Cold Instrument Functional Overview

R. Davies







Project Timeline

Date	Milestone
2015, Oct	Kick-Off
2017, Apr	System Requirements Internal Review
2018, Oct	Preliminary Design Review
2020	Final Design Review
2024	Preliminary Acceptance in Europe

MPIA Team & WPs

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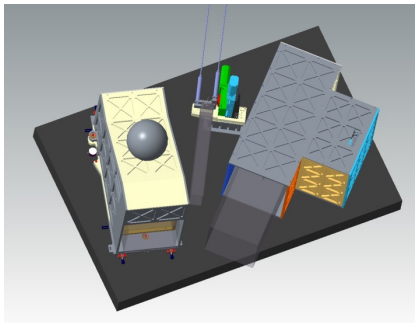
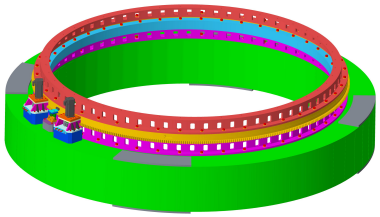
TechDept: Vianak Naranjo, Udo Neuman, Jose Ramos, Lars Mohr, Ralf-Rainer Rohloff, Norbert Münch, Ulrich Grözinger, Conchi Cardenas, Peter Bizenberger

ScienceDept/Associates/juniors: Gabriele Rodeghiero, Santiago Barboza, Martin Glück, Felix Bosco, Max Häberle, Enrico Biancalani, Miriam Sawczuck

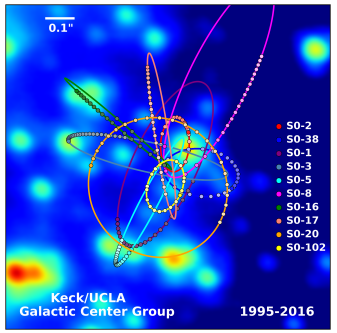
Calibration Unit



Derotator

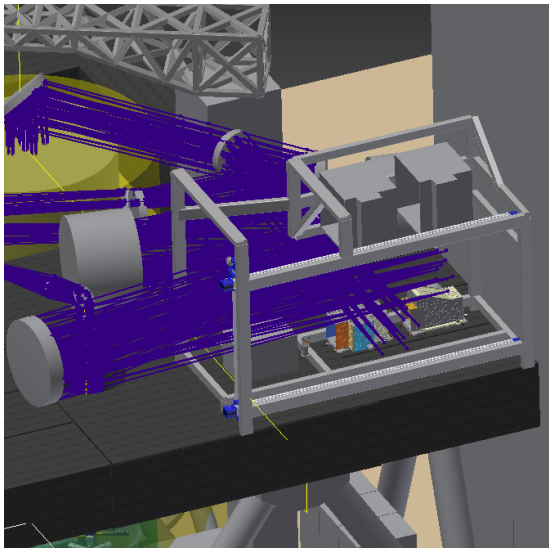


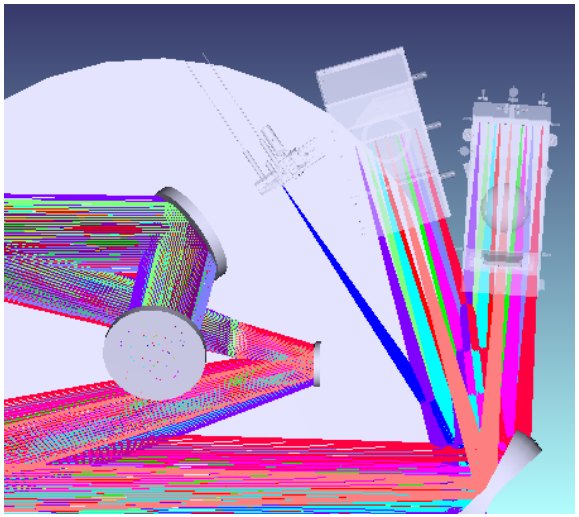
Astrometric Error Budget

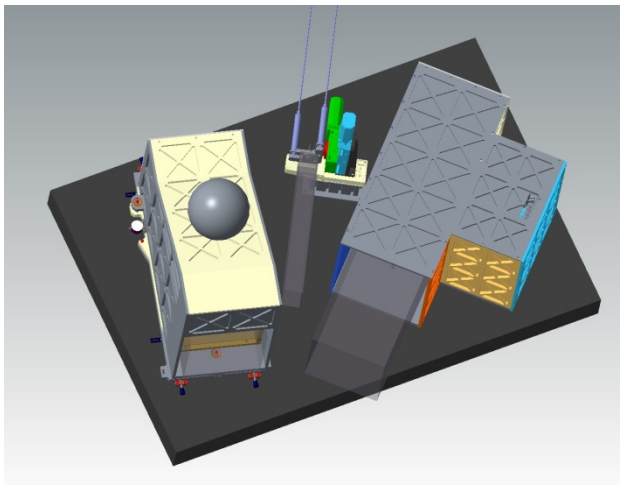


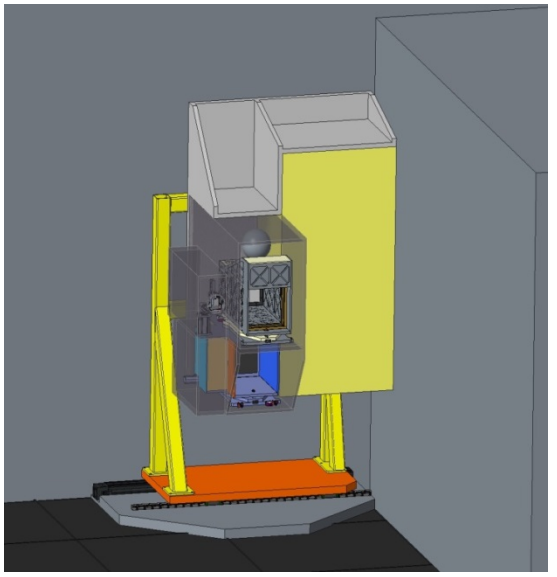
MCA deployment mechanism design & IF

MCAO MAORY mode & **Standalone SCAO mode**



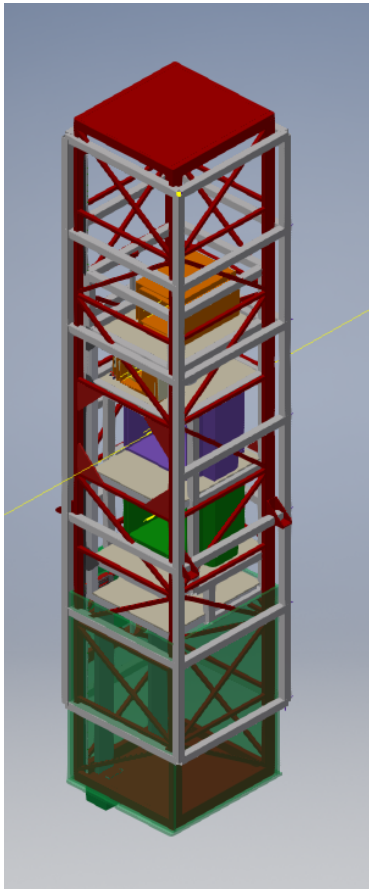




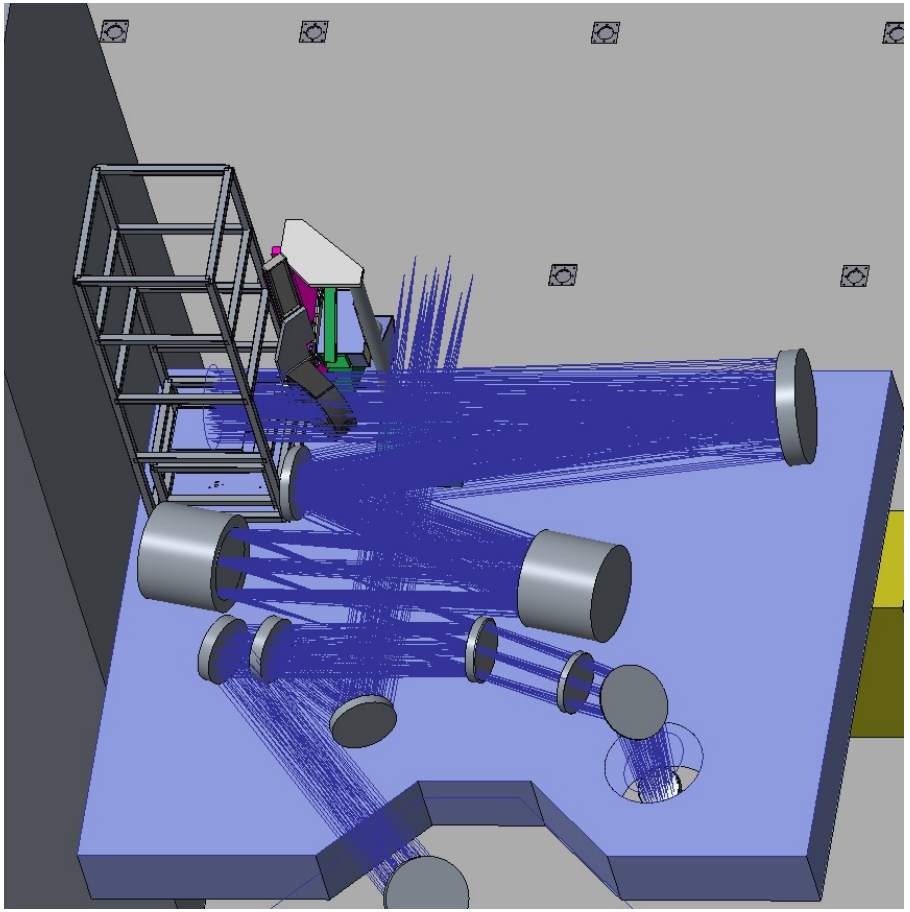


Two parallel solutions

- **Elevator** parked below the MAORY bench
- Vertically deployed at ELT FP
- Hosting MAORY CUA, MCA, 2nd instr. CU



- **Steering mirror**
- MCA on the side of MAORY beam
- Close to ELT focal plane



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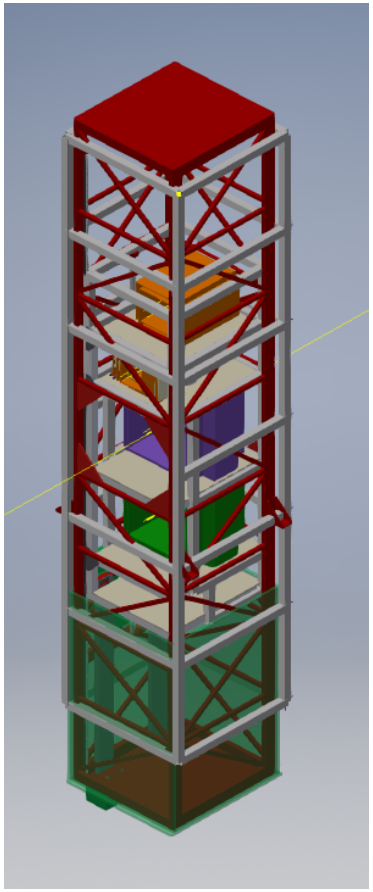

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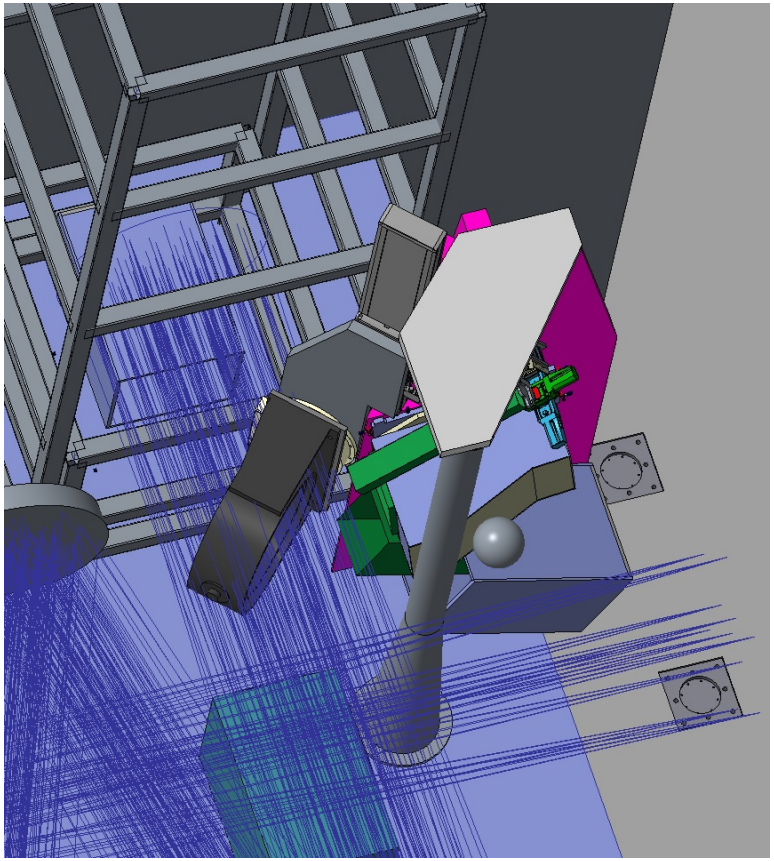
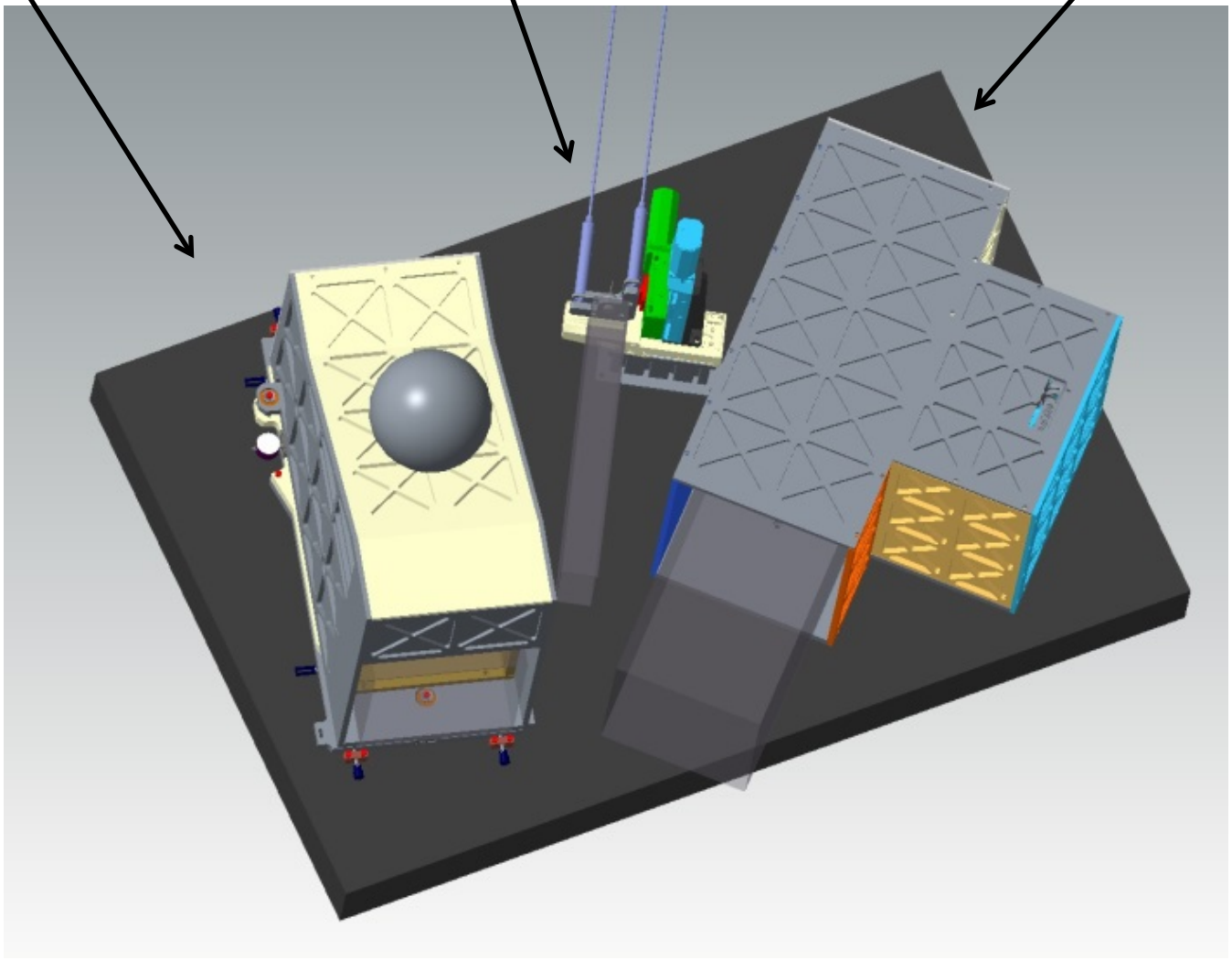


Flat-Field & wave Calibration

Movable source SCAO

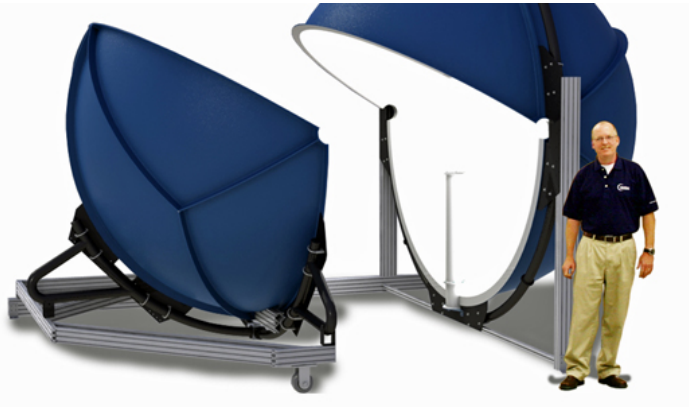
Astrometric Calibration

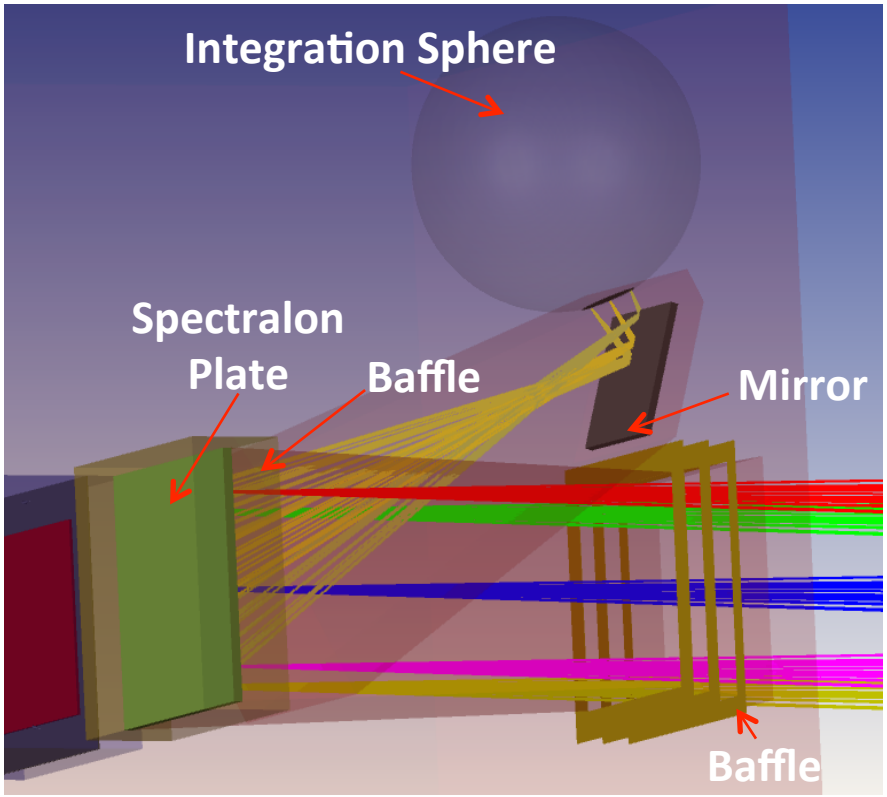


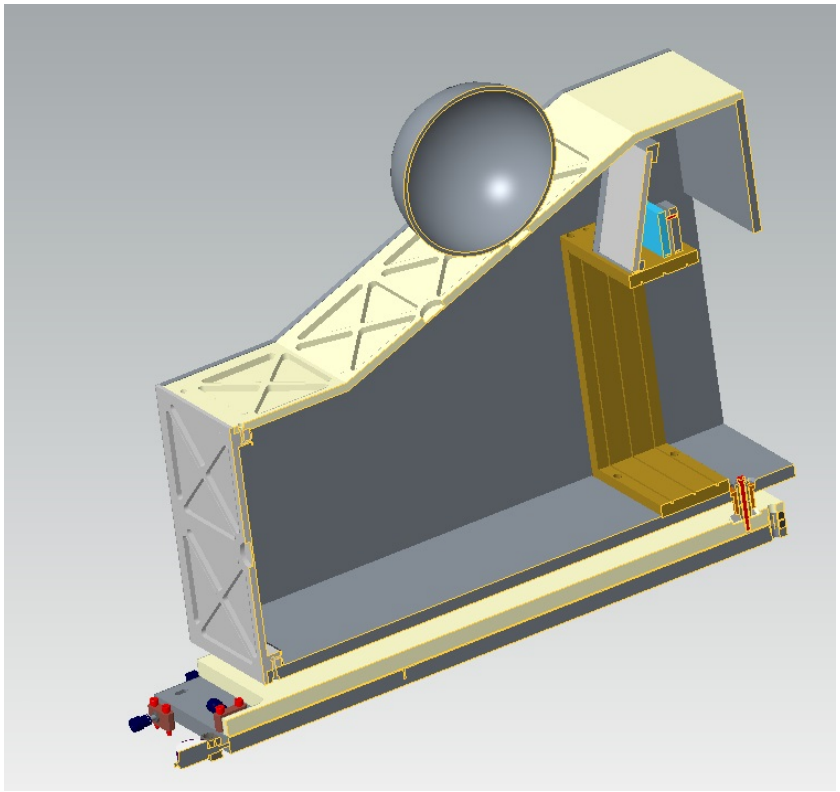
MCA Flat-Field & Wavelength Calibration Unit

- **Flat-Field** continuous white light source
- **Detector response**
- **Quantum efficiency**, pixel to pixel variations, hot/dead pixels
- **Vignetting factors**

- Tungsten lamp, 10 W inside an integrating sphere
  + large Spectralon panel



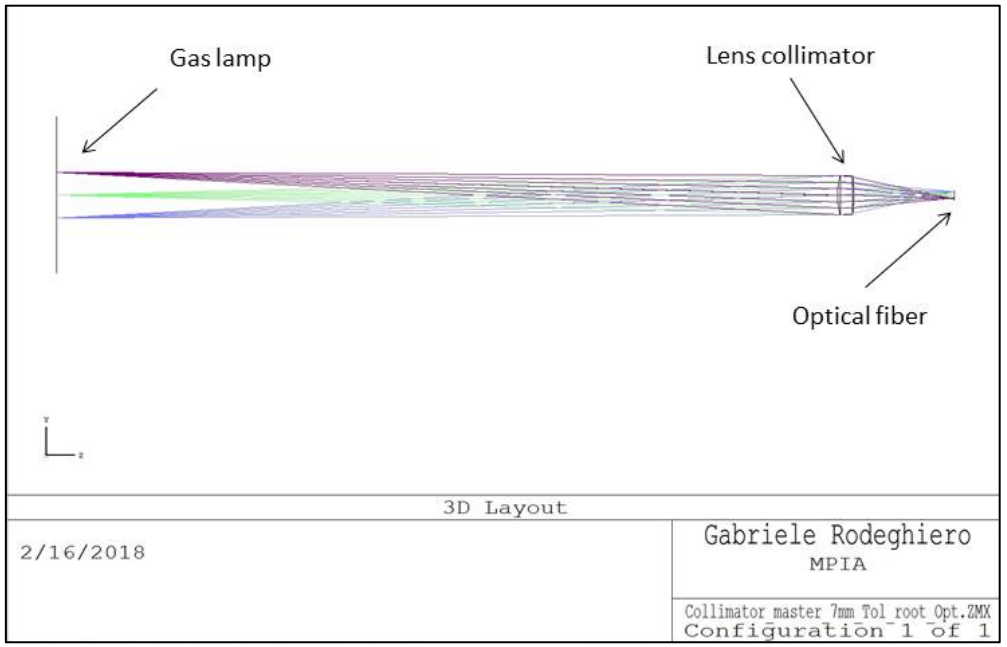


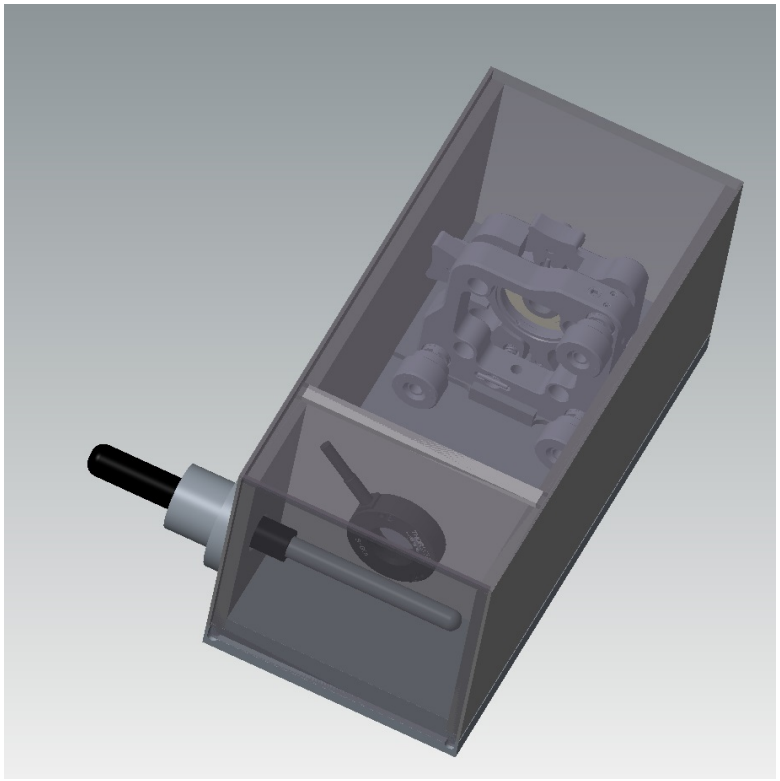


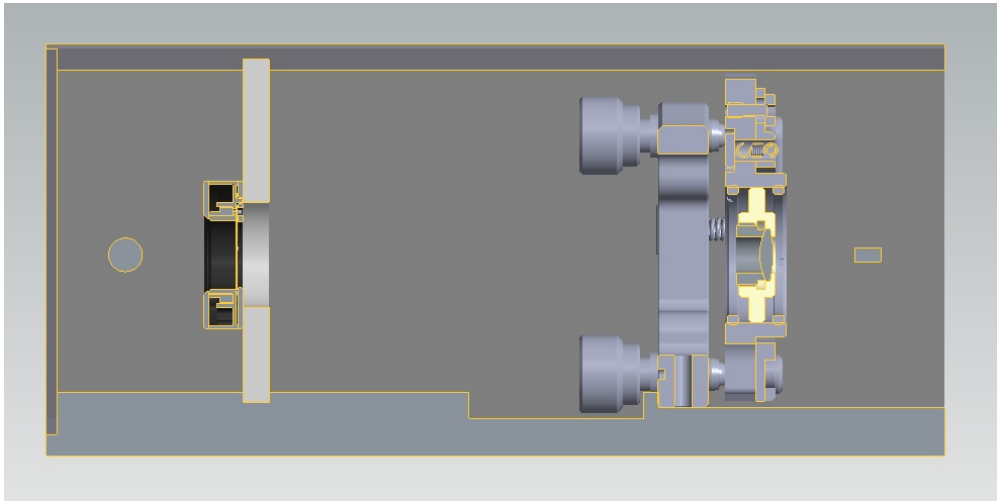
MCA Flat-Field & Wavelength Calibration Unit

- **Wavelength Calibration**
- Emission line spectrum gas lamps
- **Wavelength solution** of spectrograph
- **Line geometry**

- 4 gas lamps, **Ar**, **Kr**, **Xe**, **Ne**

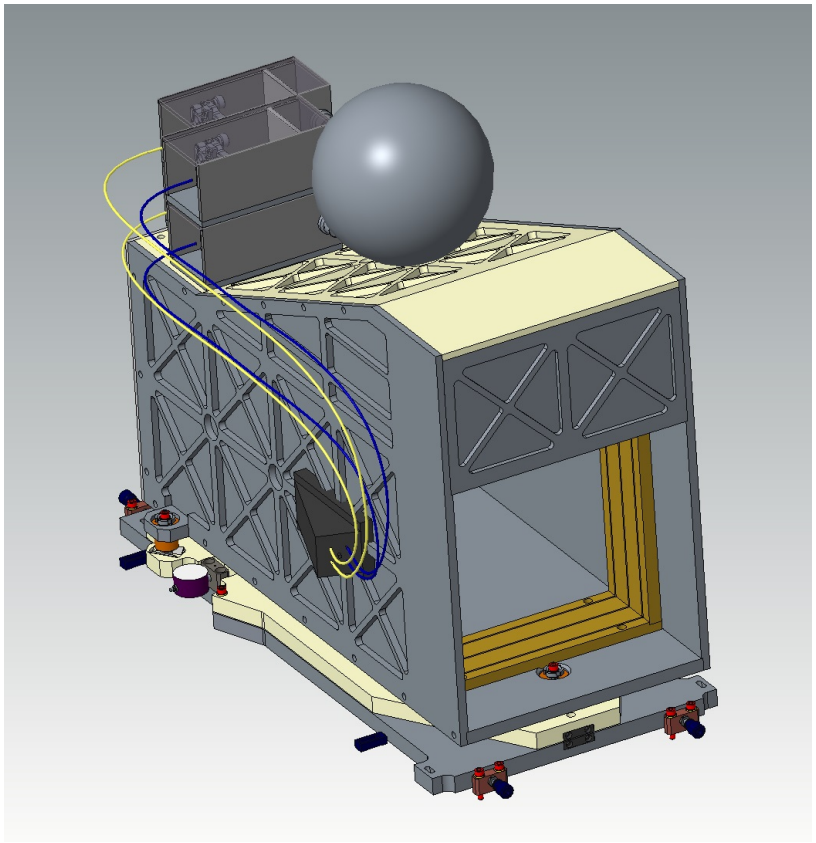


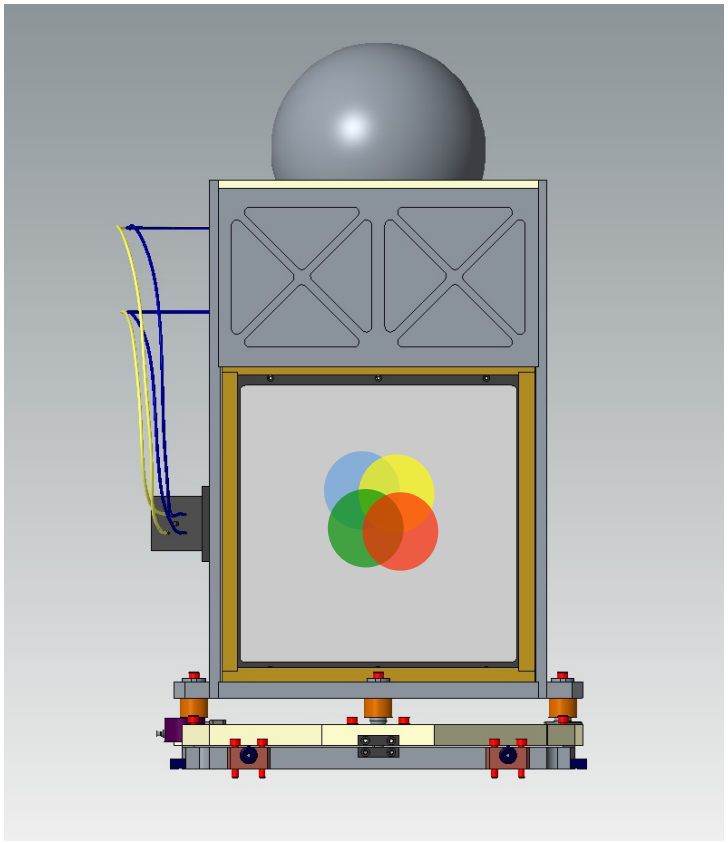




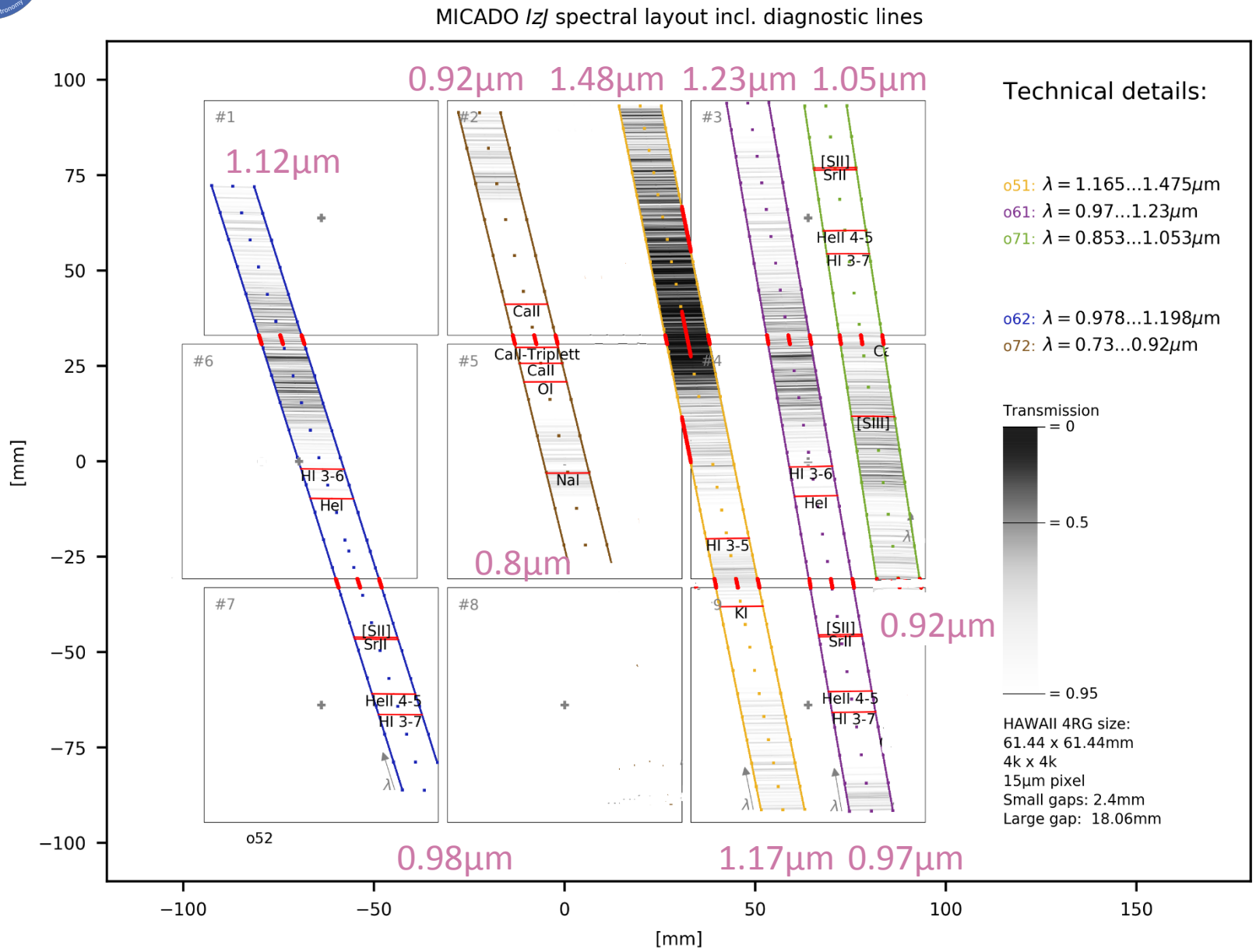
MCA Flat-Field & Wavelength Calibration Unit

- The lamps bypass the integrating sphere
- Equalize lamps flux
- Use only certain lamps





IzJ spectral layout with 3” slit

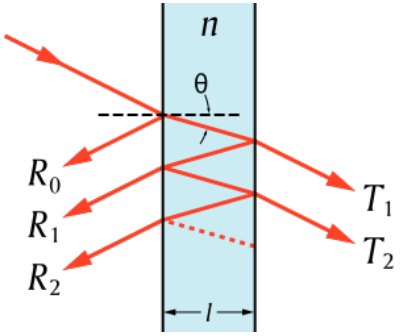


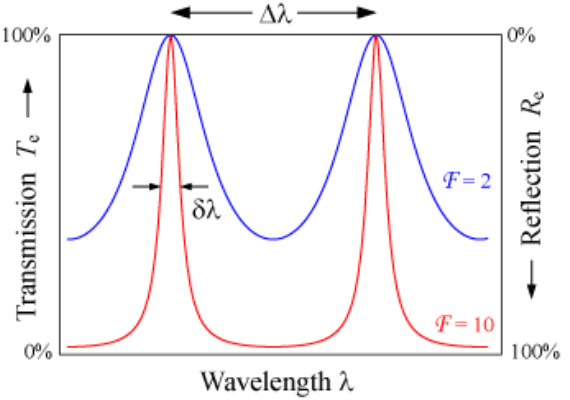
MCA Flat-Field & Wavelength Calibration Unit

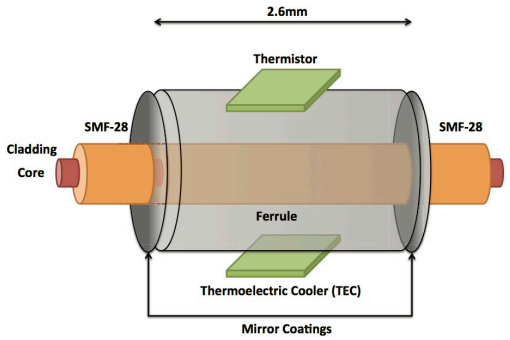
- Possible upgrade
- Relative wavelength calibration
- Fabry-Perot etalons

2 solutions

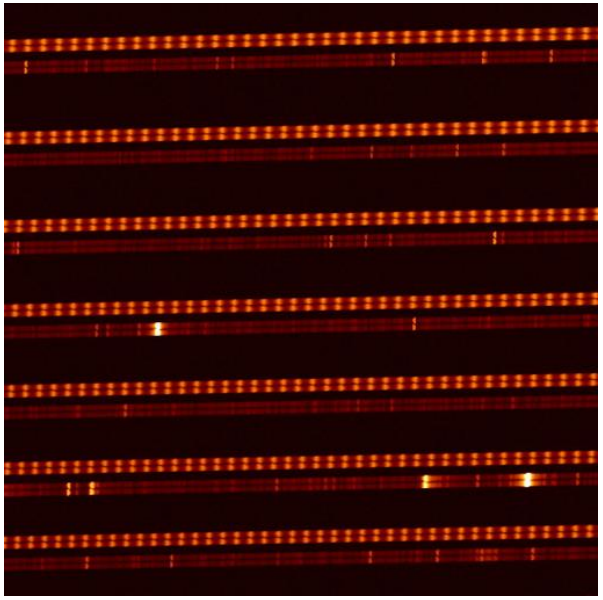
1) Macroscopic cavity+Tungsten lamp
2) SM fiber + supercontinuum laser



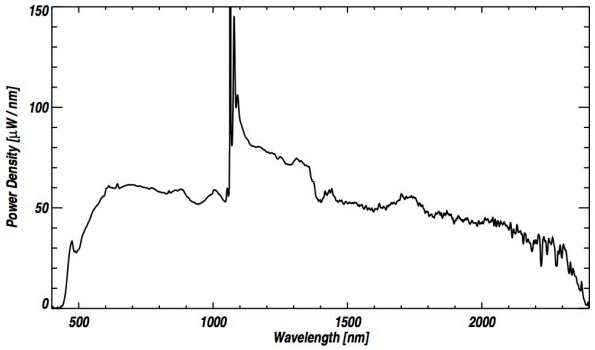




FP+UNe, Carmenes 3 Apr 2015

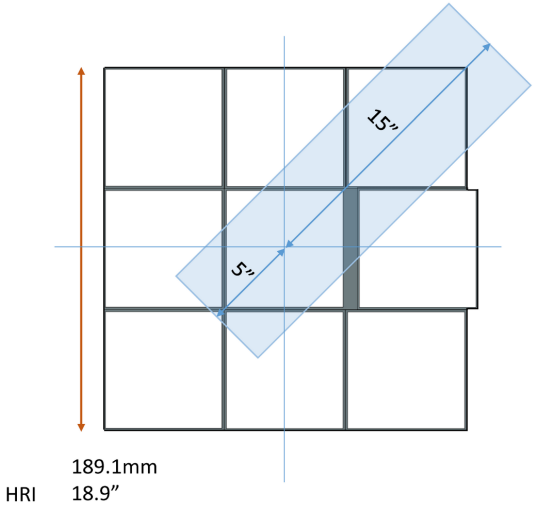


Class IV laser



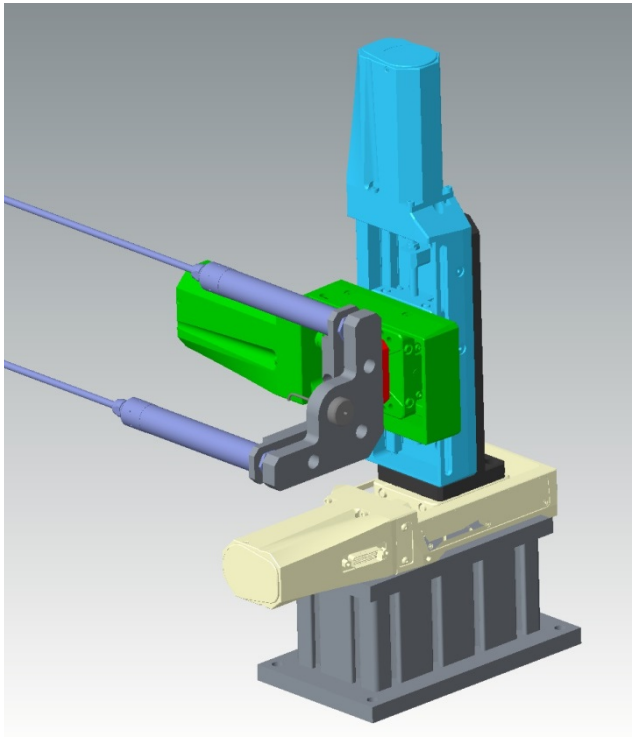
Halverson et al. 2014

MCA SCAO movable source



Diffraction-limited source

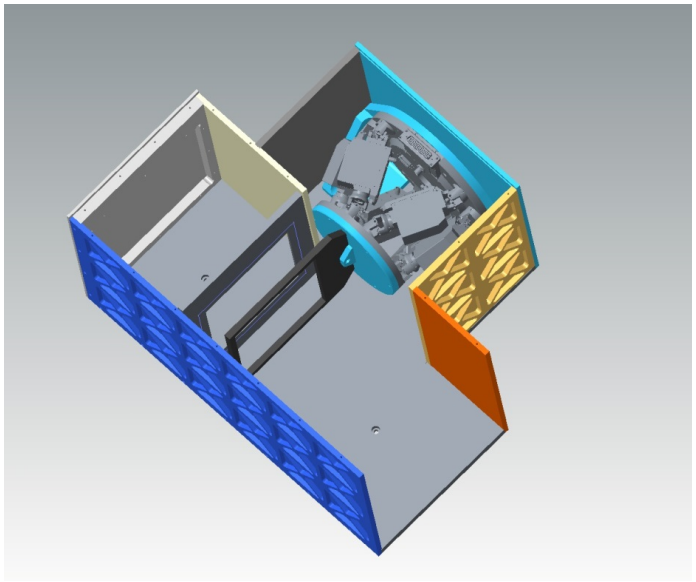
- Optical fiber positioned by 3 linear PI stages + Tip-Tilt stage
- Calibrate SCAO WFS for differential tracking observations
- Identify derotator-GD rotation axis at every cryostat dismounting
- Patrol SCAO FoV 40 x 80 mm linear range



Requirements

- Diffraction-limited, wavelength 0.5-1.5 µm, tunable flux
- DoF: x,y patrol the field, z refocus + tip-tilt
- Maximum speed 100"/h -> 0.09 mm/s @ ELT FP

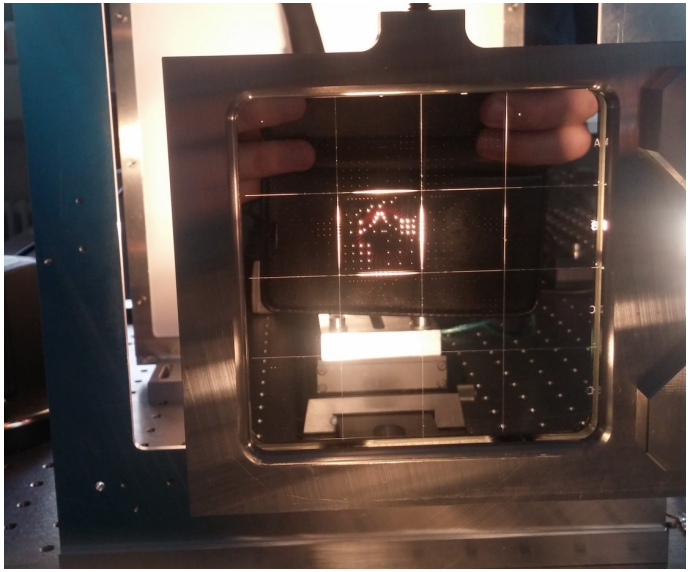
MCA Astrometric Calibration Unit

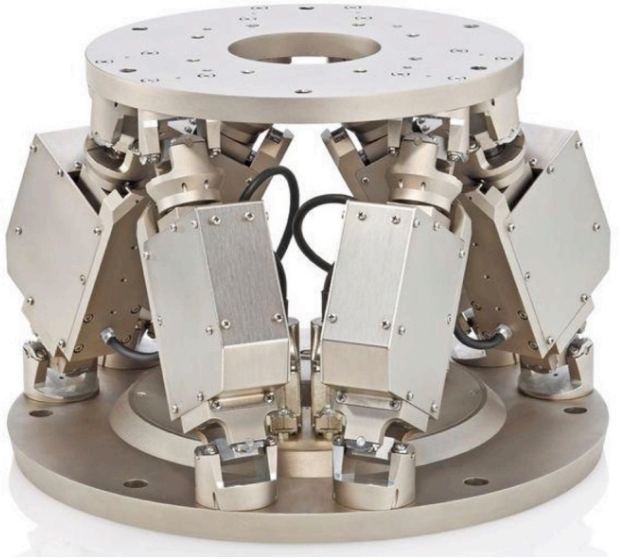


Map optical distortions & drift inside MICADO and MAORY
Map intrapixel sensitivity

Warm Astrometric Mask
- Back-side illuminated
- Etched pinholes on a Chrome coated Zerodur substrate

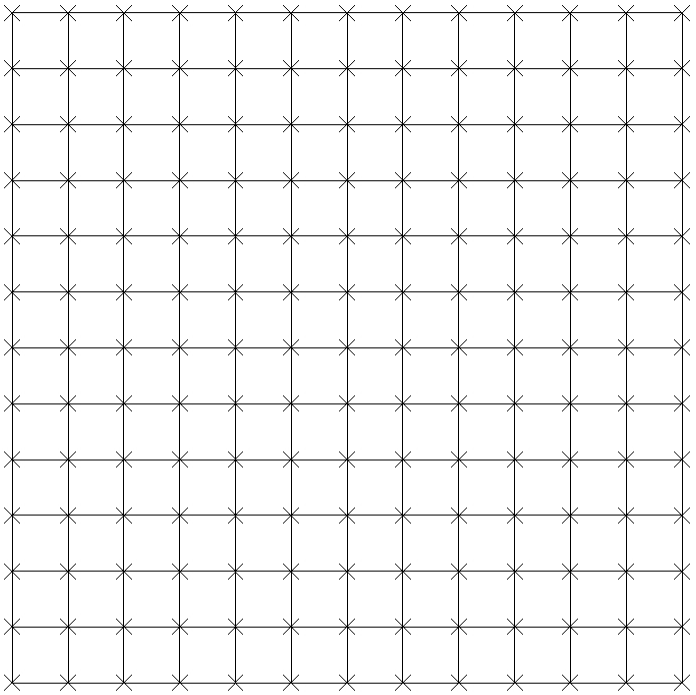
6 DoF for **Alignment**, **Focus** & **Dithering**
Repeatability to ±0.1 µm / ±2.5 µrad





MCA Astrometric Calibration Unit

WAM pattern



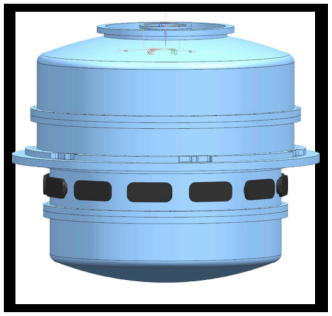
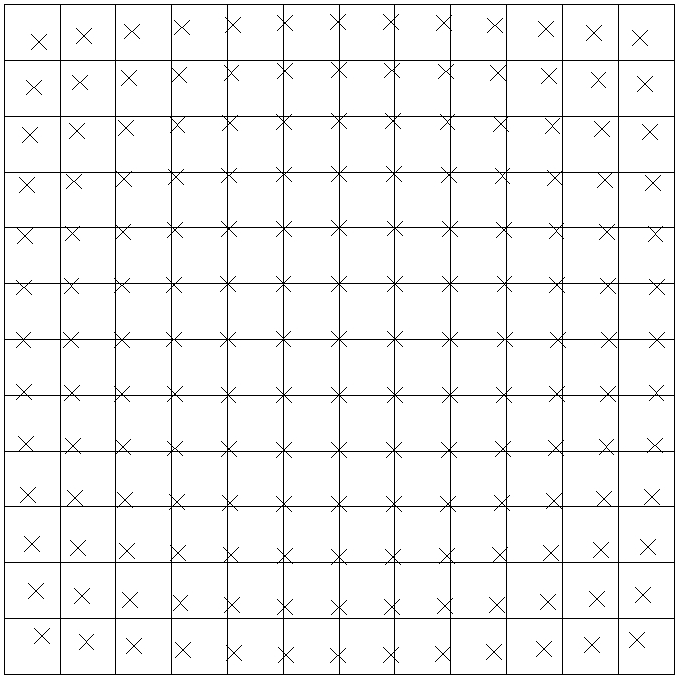
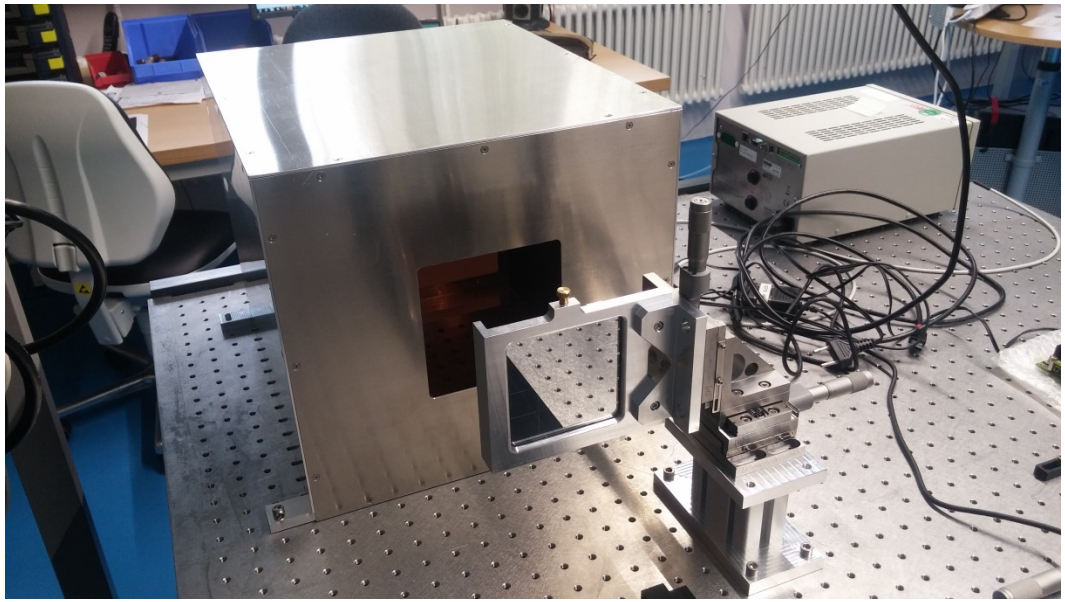
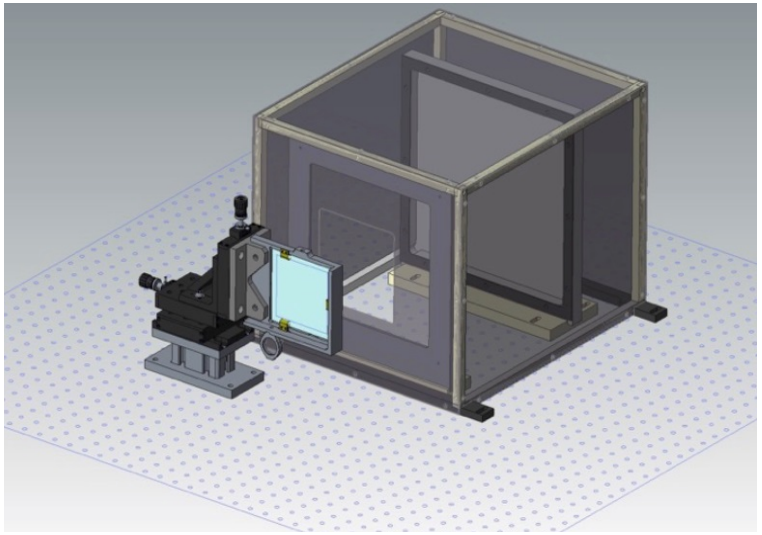


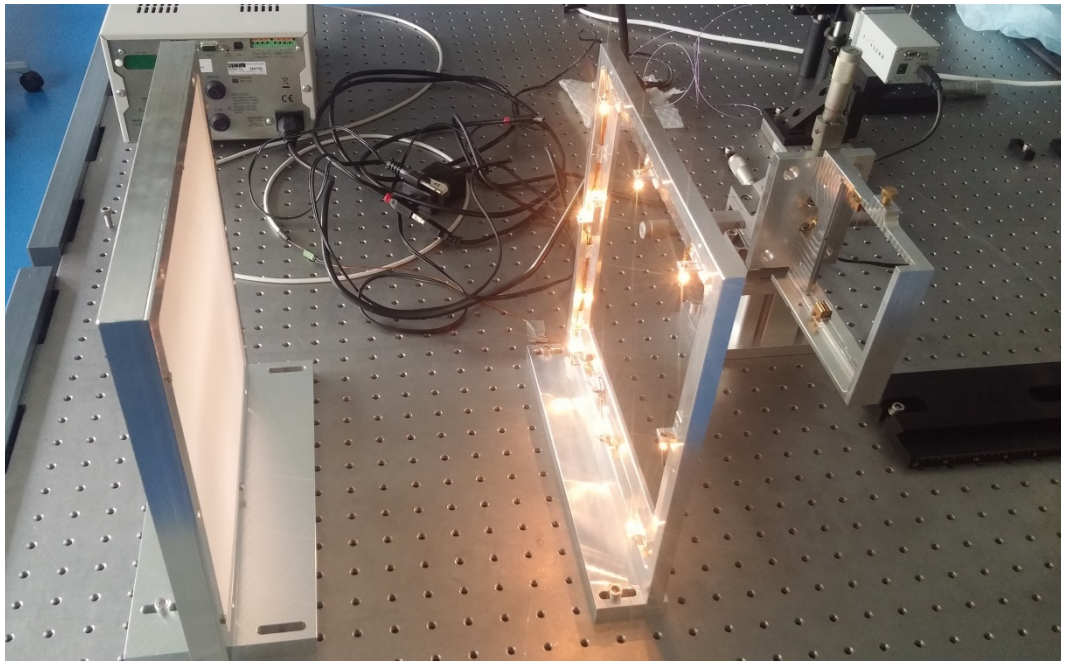
Image of WAM with MICADO



WAM prototype Test Plan







MCA astrometric unit dummy

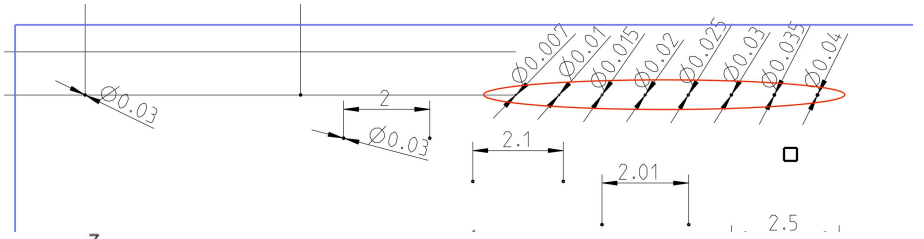
WAM prototype scale 1:2

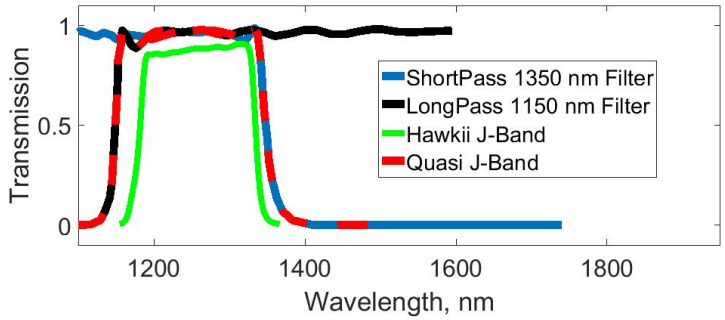
- Assess manufacturing
- Pinholes positions
- SNR calibration frame
- Aging of coating

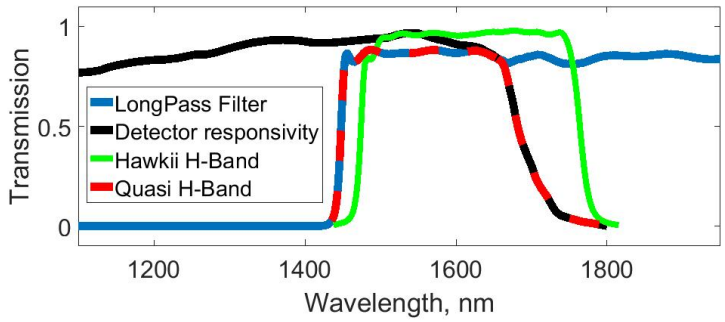
WAM prototype Test Plan

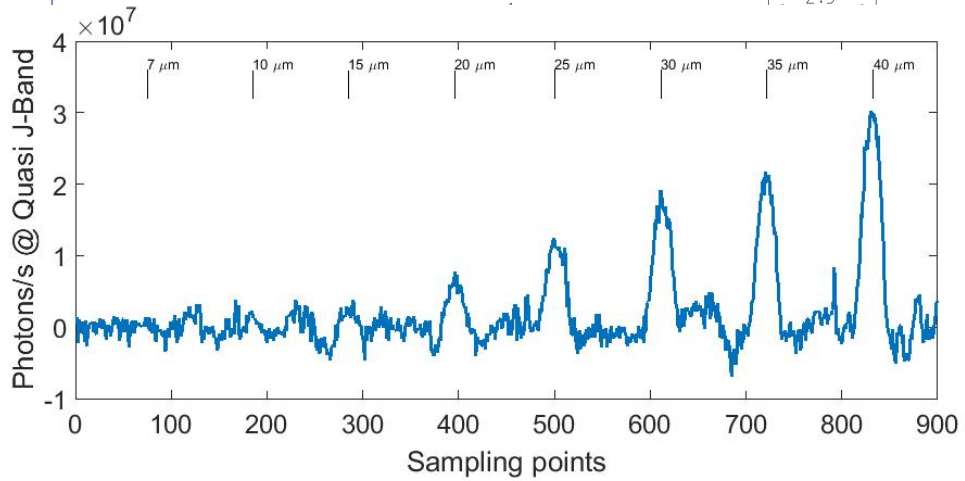
- Estimate absolute flux from pinholes
- Find best pinhole diameter

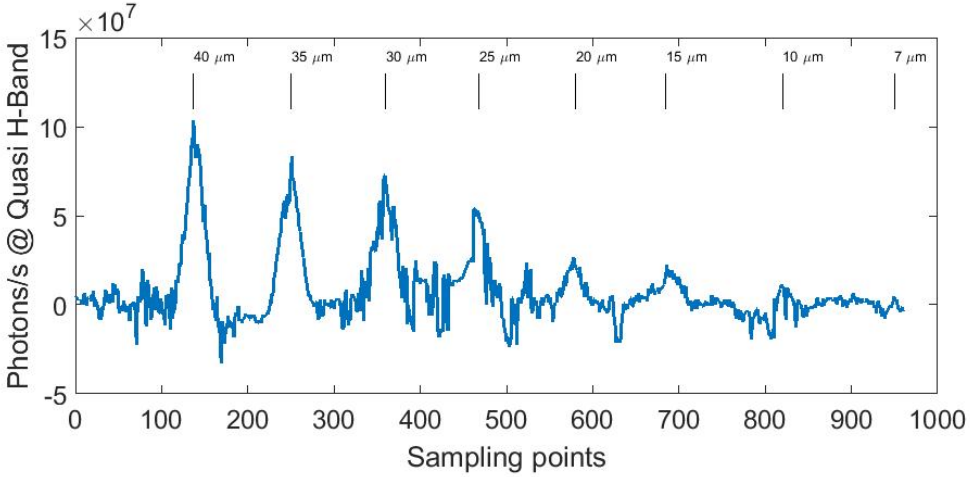
Goal: astrometric calibration 10-20 sec











Relative Astrometry with ELTs

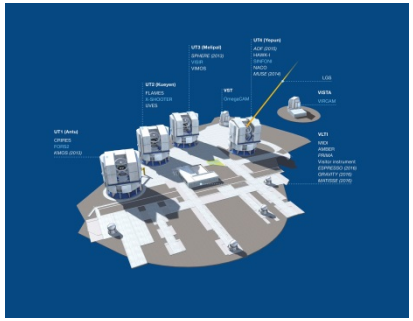
VISION -> Relative astrometry at **50 μas** level

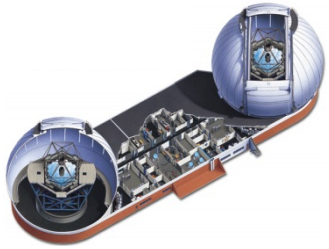
$$\sigma = \frac{FWHM}{SNR}$$

VLT / 5

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

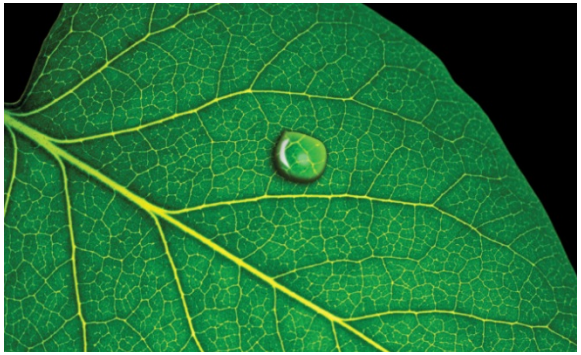
25 x VLT





Telescopes **5** times bigger
smaller *FWHM* & higher *SNR*
<u>BUT</u>
stability issues

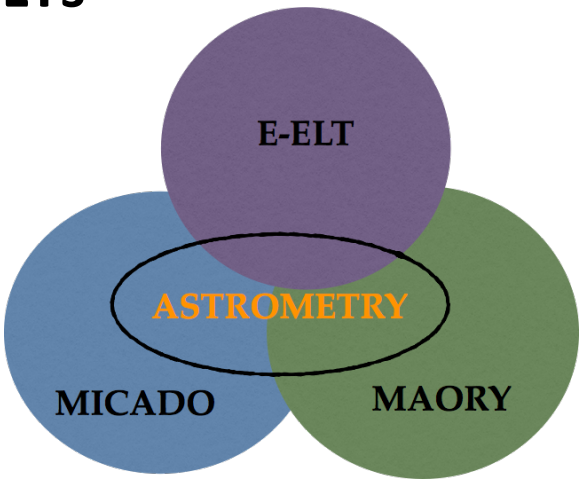
Distortion(t)

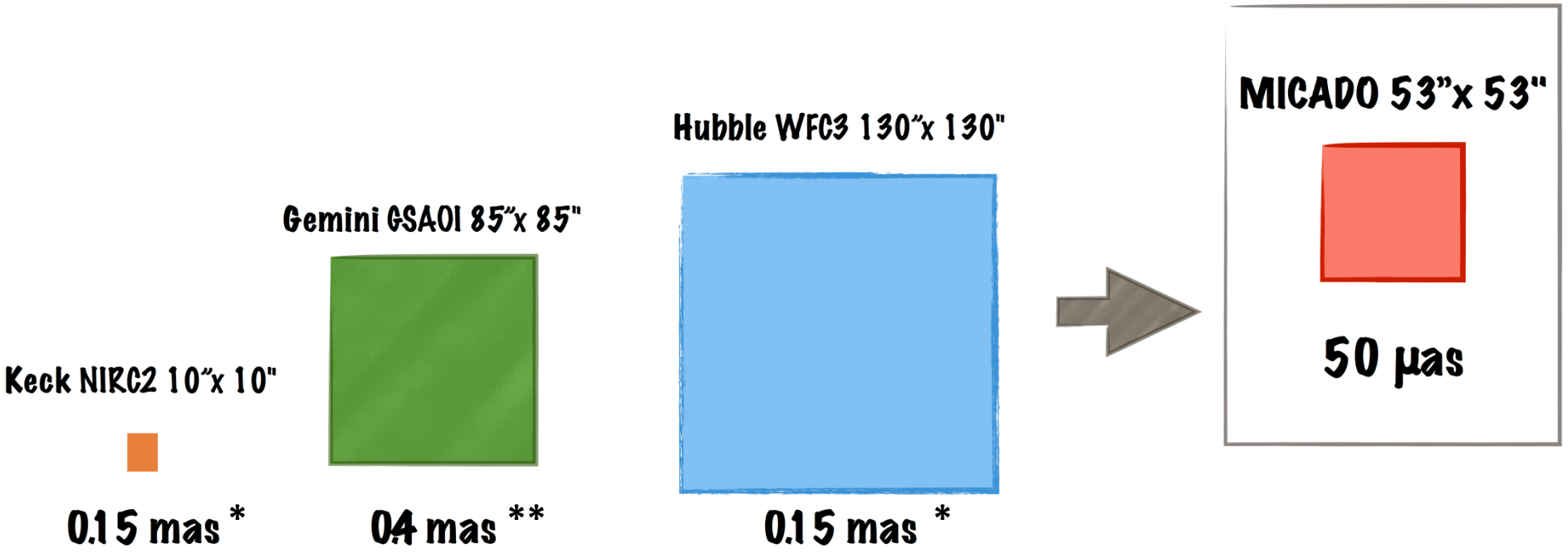


Relative Astrometry with ELTs

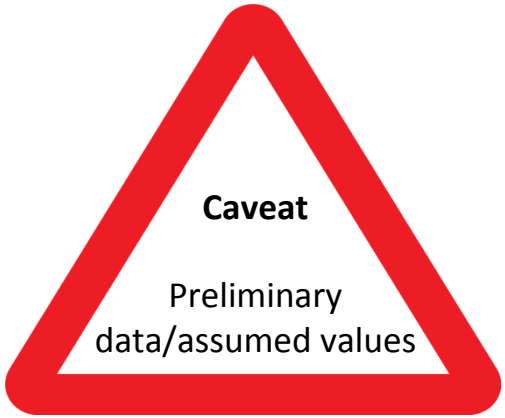
- Current instrument astrometry noise floor **0.15**-**0.4** mas
- NIRC2 **SCAO**
- WFC3 Space
- GeMS **MCAO**

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

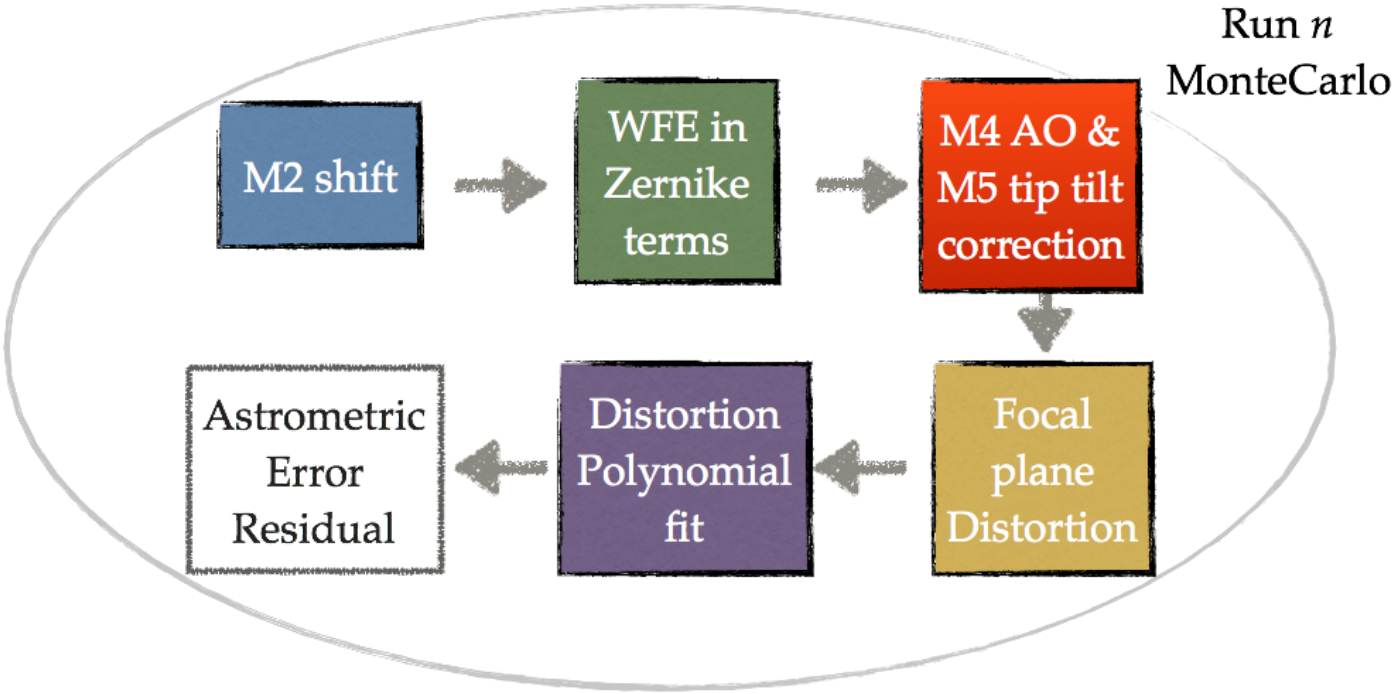




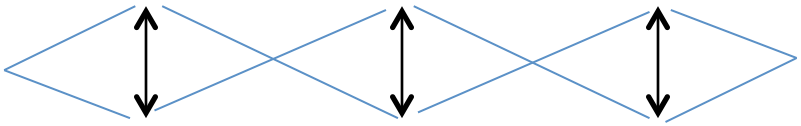
MC tolerances approach



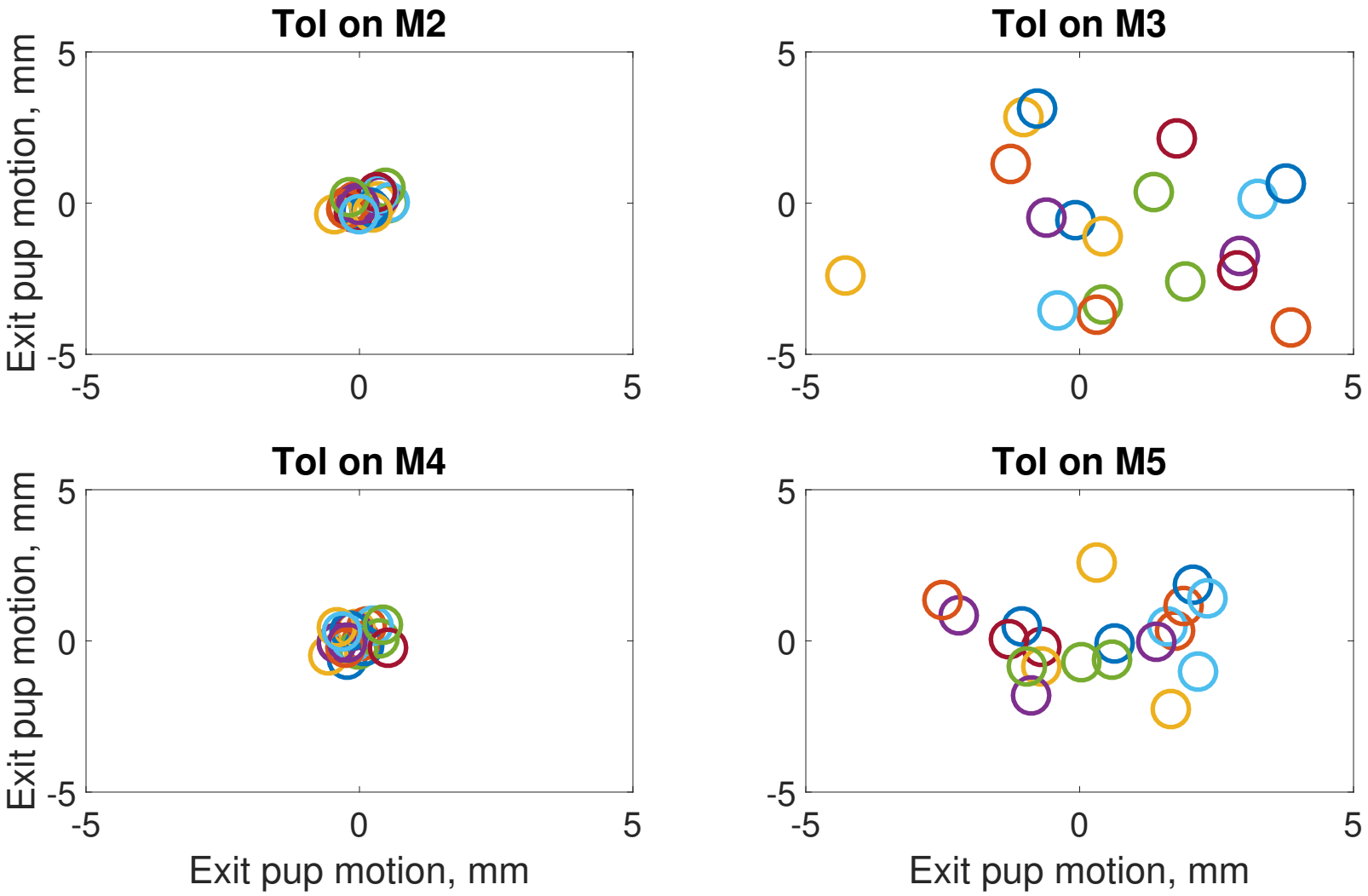
- OpticStudio (Zemax) ZOS-API using Matlab



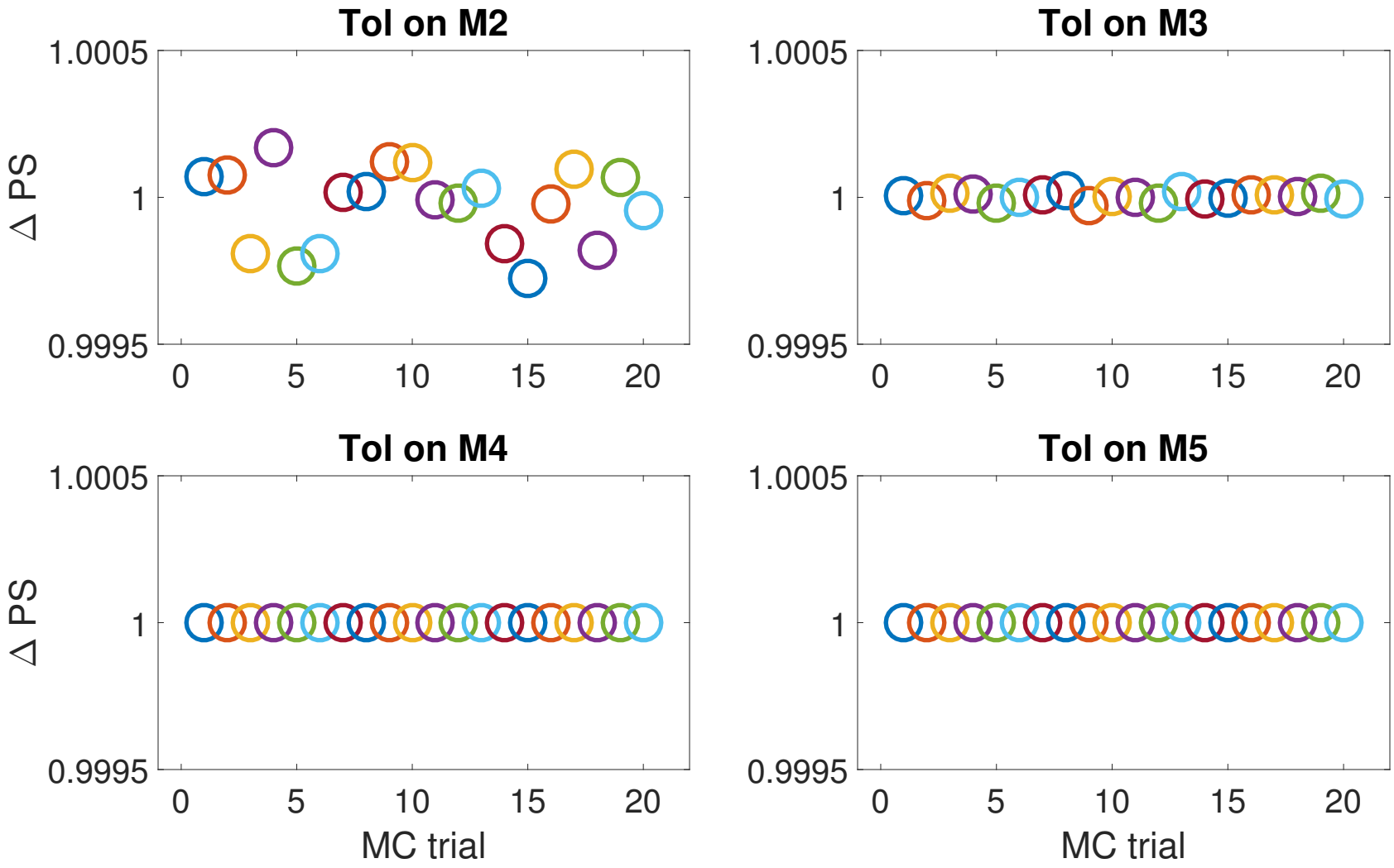
E-ELT MAORY MICADO



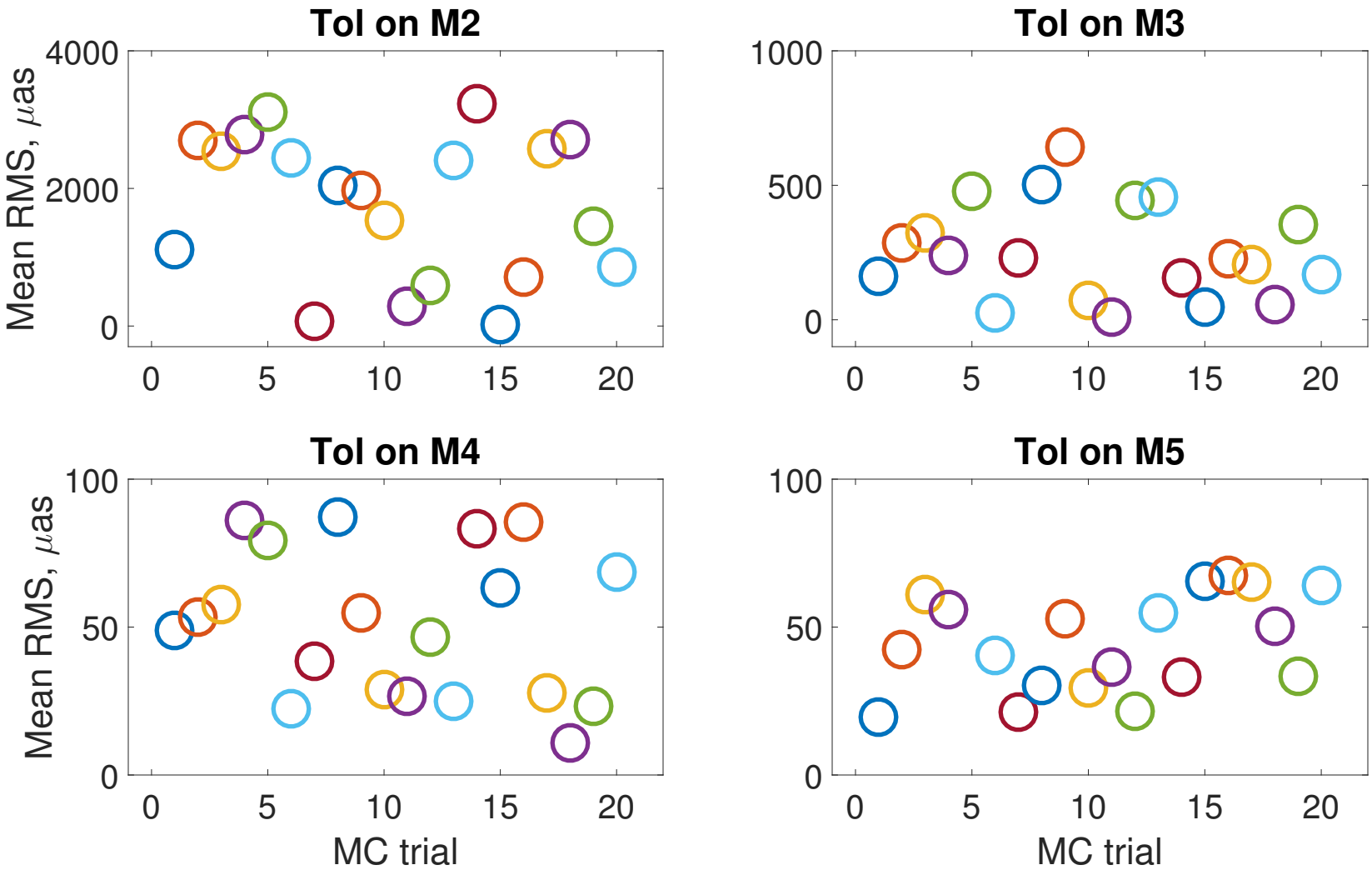
Astrometric Error Budget summary



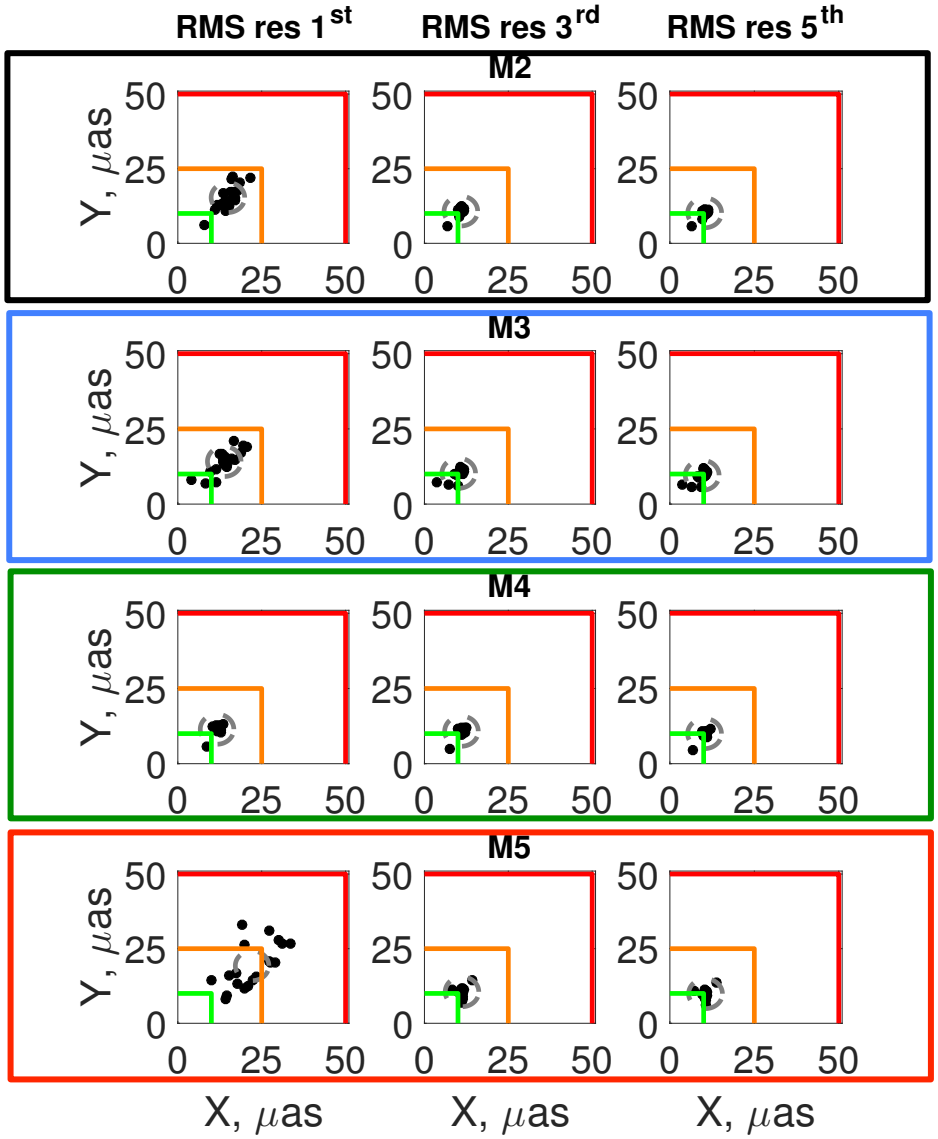
Astrometric Error Budget summary



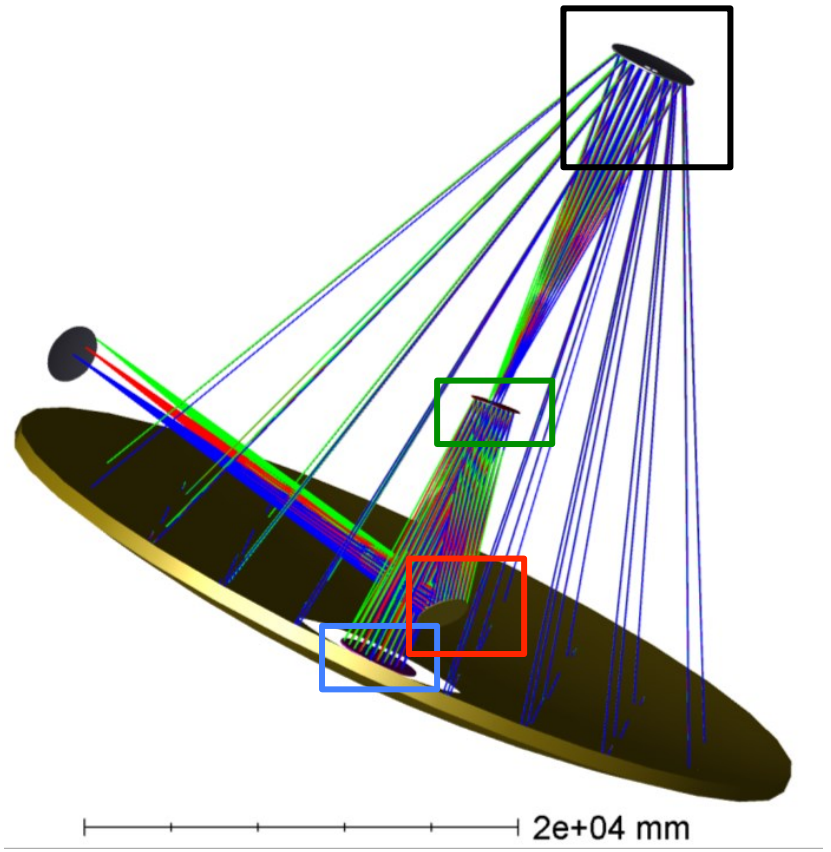
Astrometric Error Budget summary



Astrometric Error Budget summary

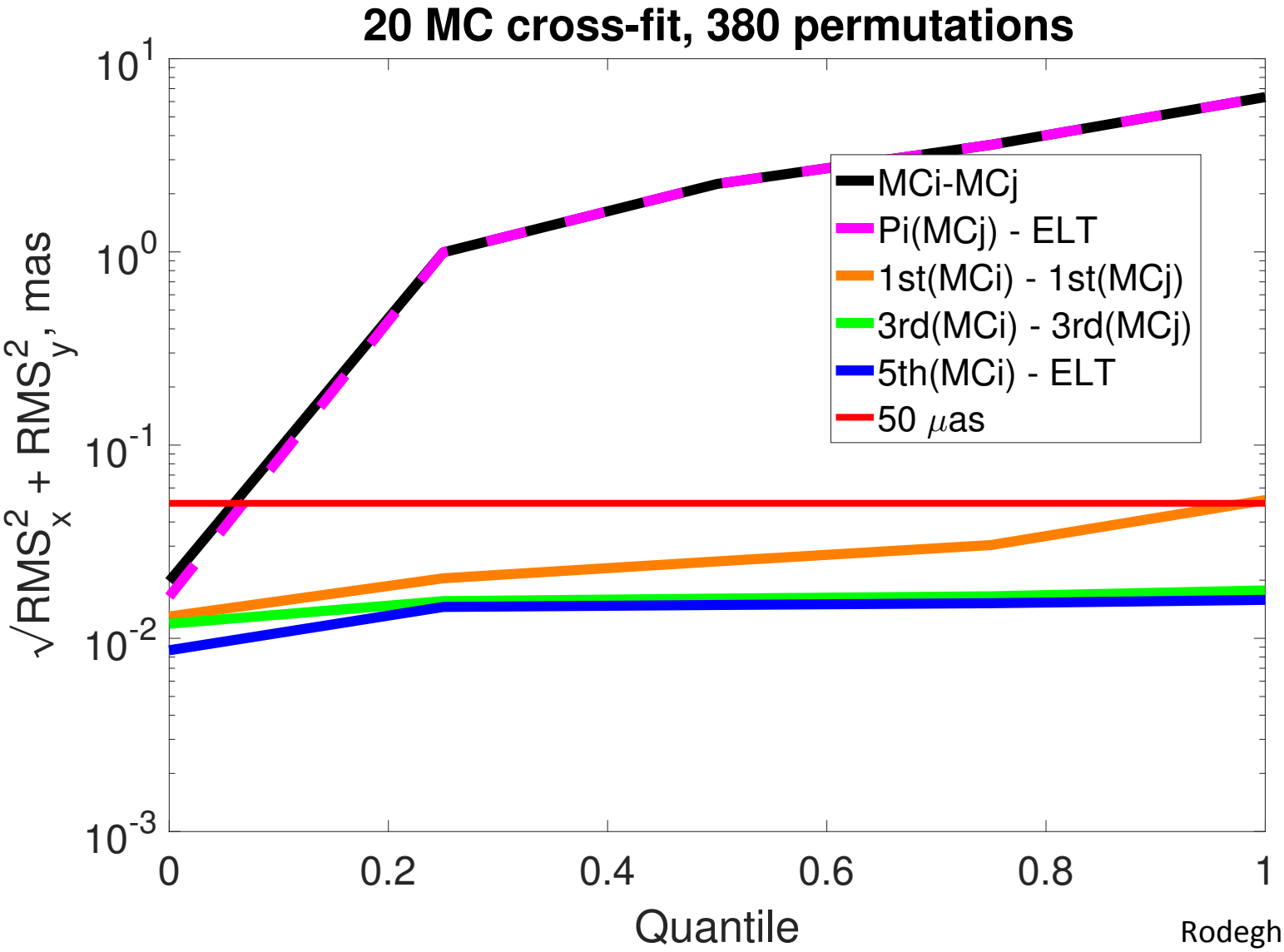


$$U = A_1 + A_2X + A_3Y + A_4X^2 + A_5XY + A_6Y^2 + \ldots + A_{21}Y^5$$



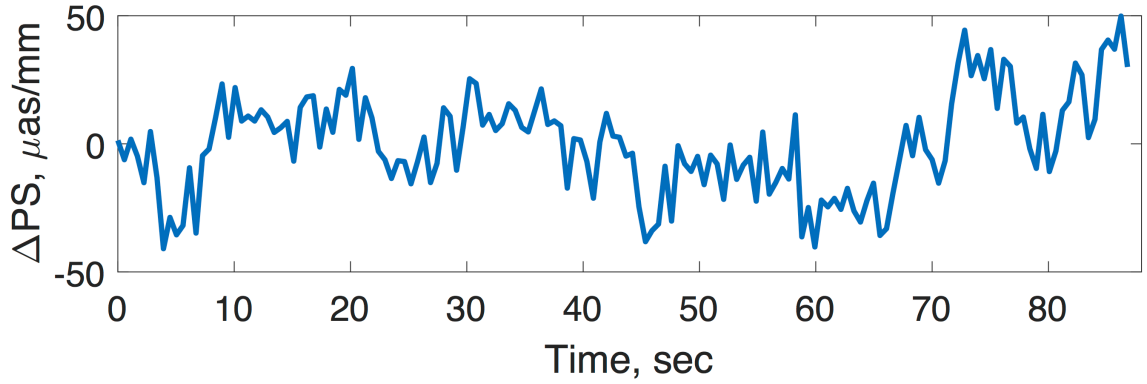
Variability of ELT distortions

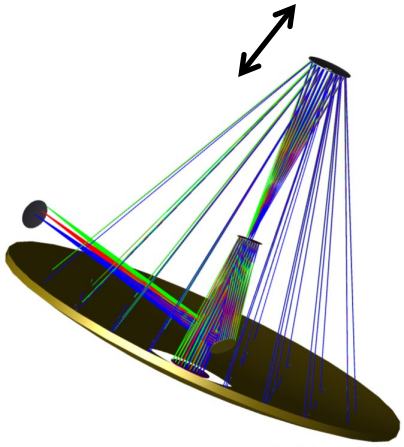
PSF jitter 5mas/arcmin



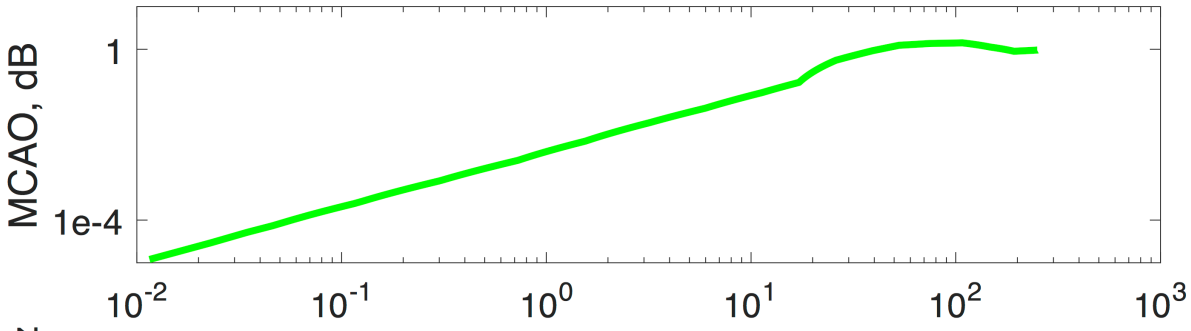
Rodeghiero, in prep.

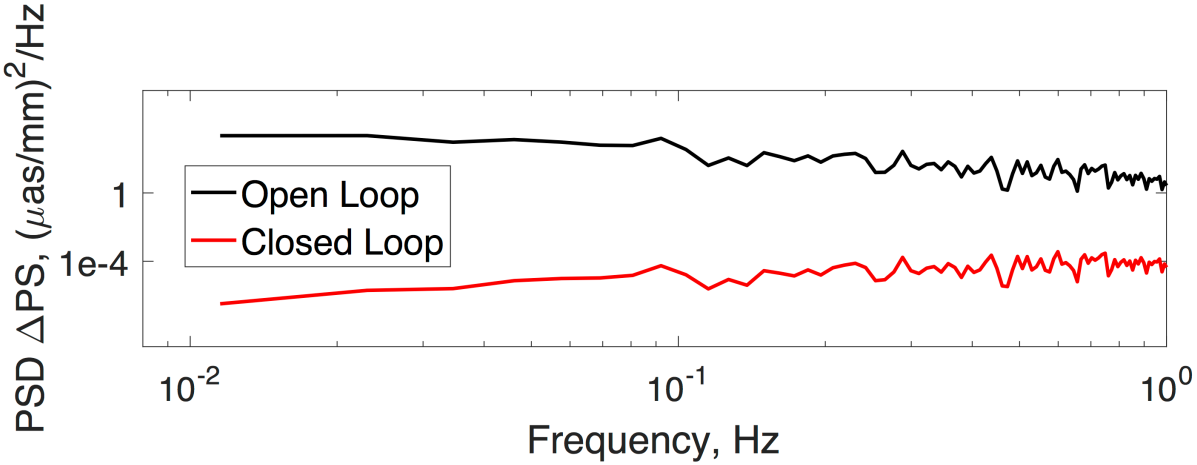
ELT PS stabilization with MCAO





9 NGS





σ ≈ 5 mas/arcmin

σ ≈ 0.04 mas/arcmin

Rodeghiero, in prep.

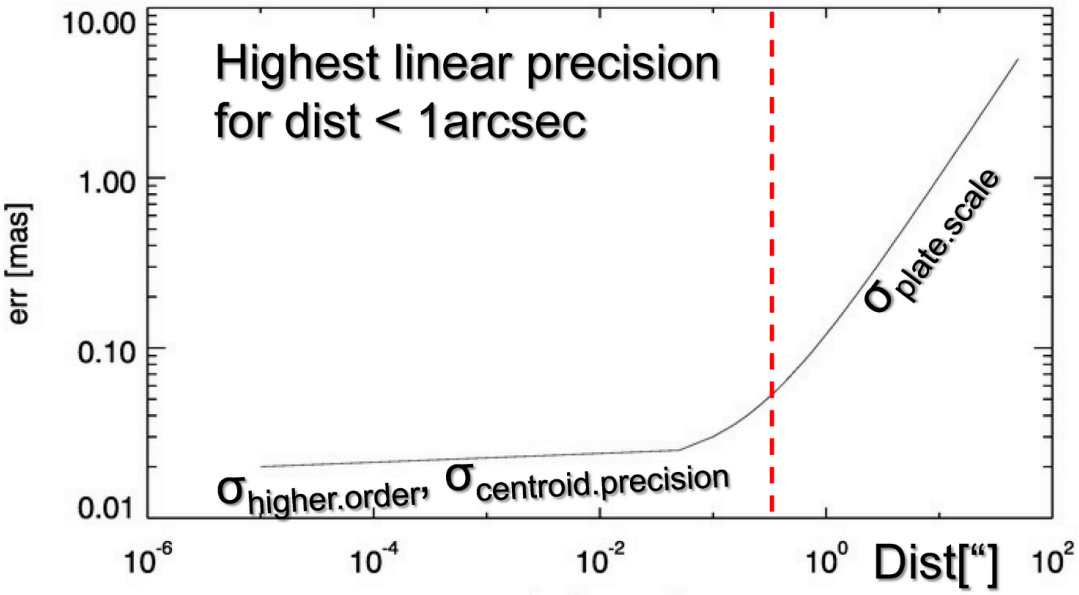
MICADO Astrometry

J-U. Pott

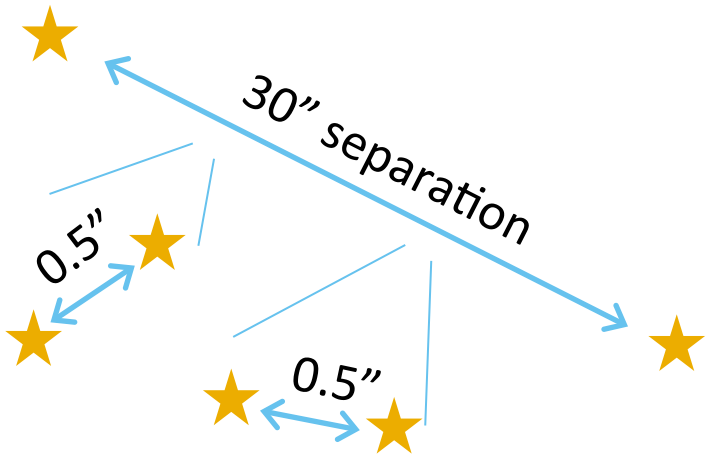
$\sigma_{plate.scale}$ ~ 10^{-4} (acts globally; drift from ELT & MAORY; ELT repeatability is 10^{-3}). Can be improved if there are good reference sources in the field

$\sigma_{3rd.order}$ ~ 100µas (acts over ~10" scales; scale of ELT distortions; should remain below $\sigma_{plate.scale}$)

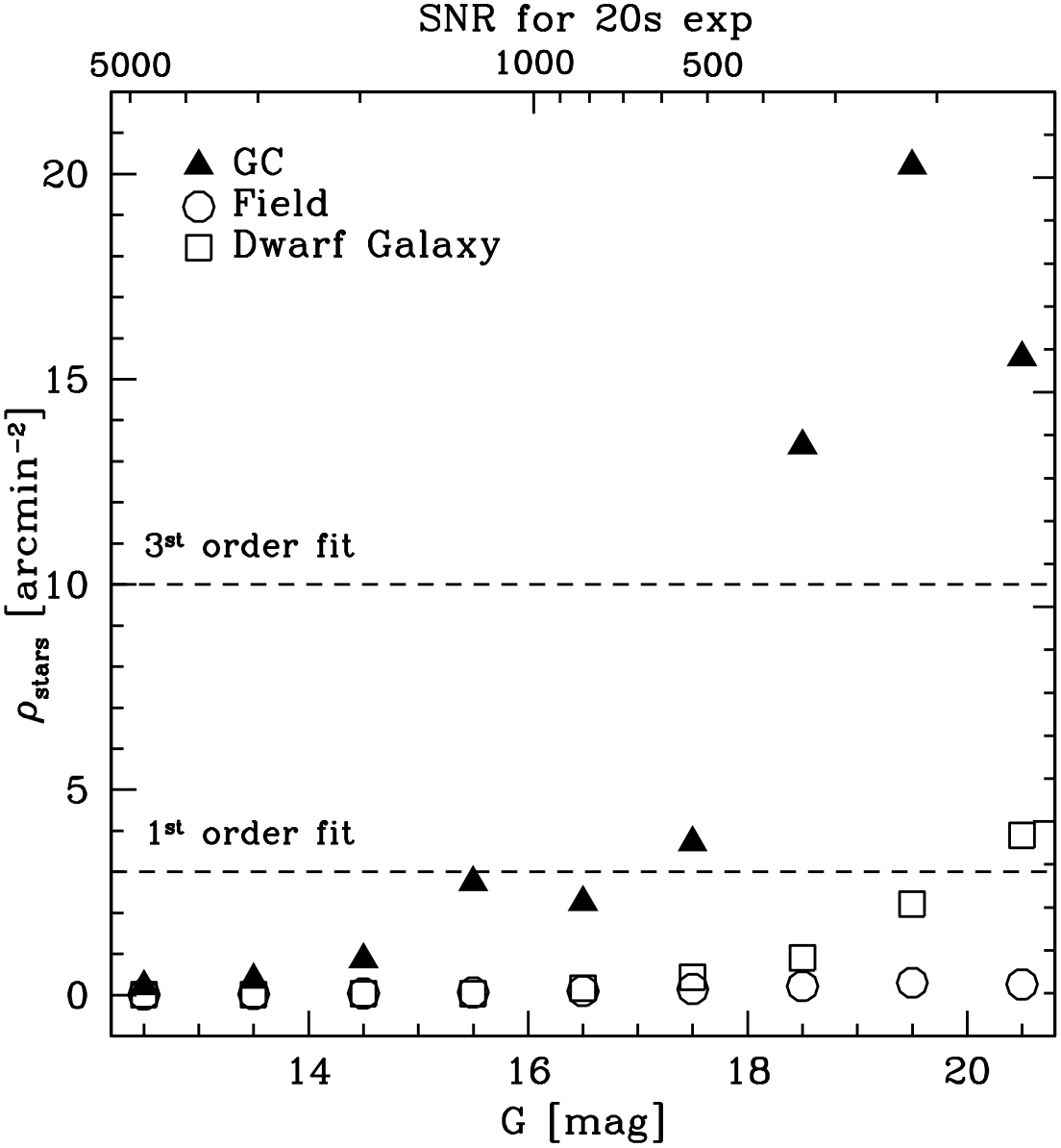
$\sigma_{higher.order}$, $\sigma_{centroid}$ ~ 10µas each (acts locally; only partially calibratable)



We *can* measure the separation of 2 stars within any local region with <50µas precision.

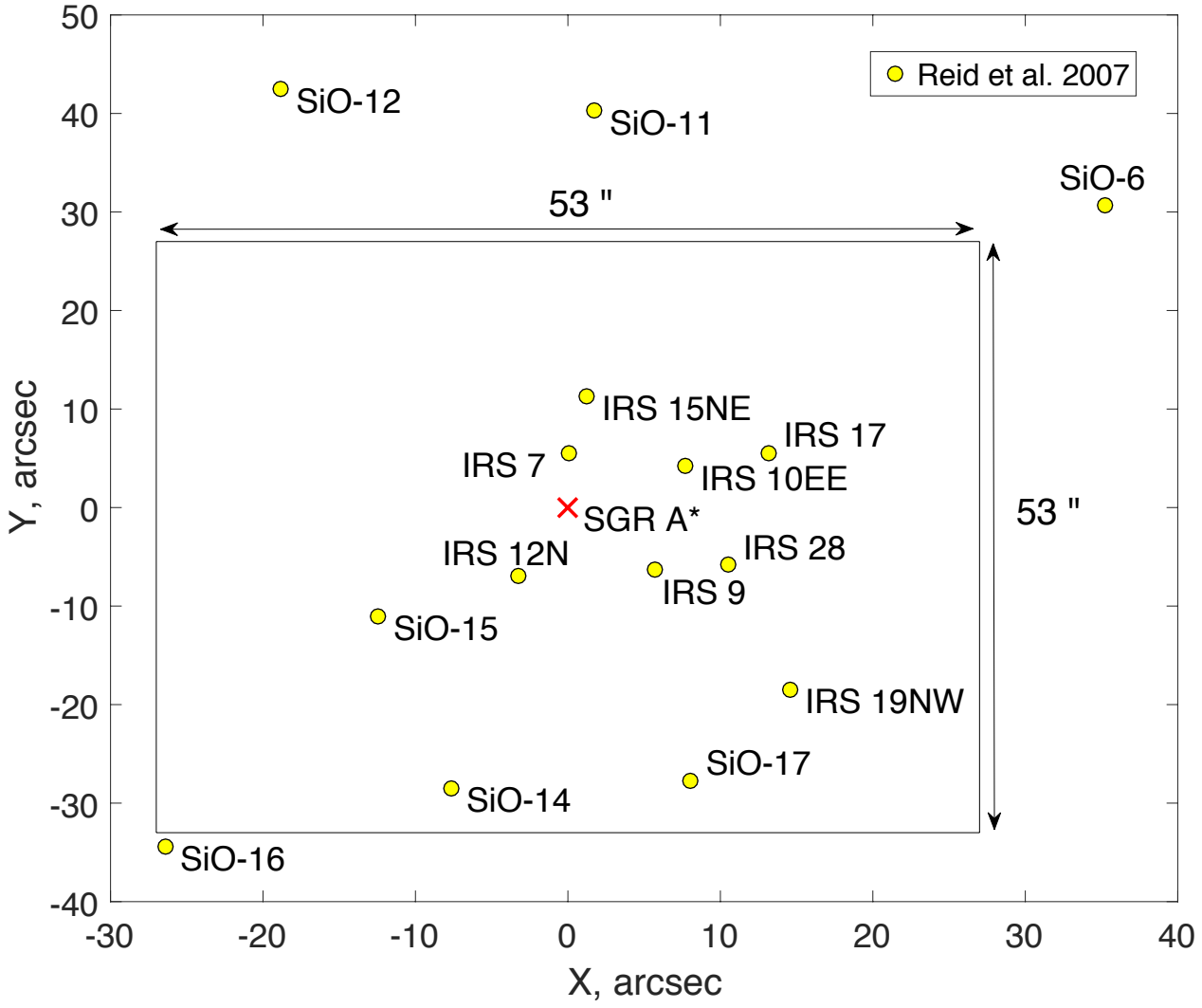


ELT on-sky calibration



ELT **Exposure Time Calculator**

ELT on-sky calibration



DANKE!