Preliminary design of the MAORY Calibration and Test Unit (CTU)

Ivan Di Antonio[1,2], G. Di Rico[2], M. Dolci[2]

[1] University of Roma Tor Vergata
[2] INAF – Osservatorio Astronomico d'Abruzzo

Wavefront sensing in the VLT/ELT era, 4th edition

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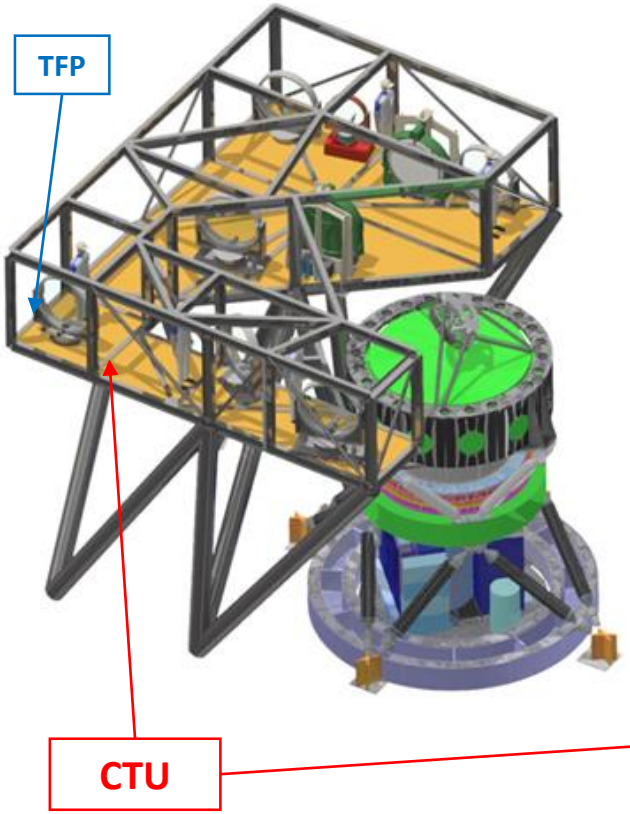
MCAO for ELT: MAORY

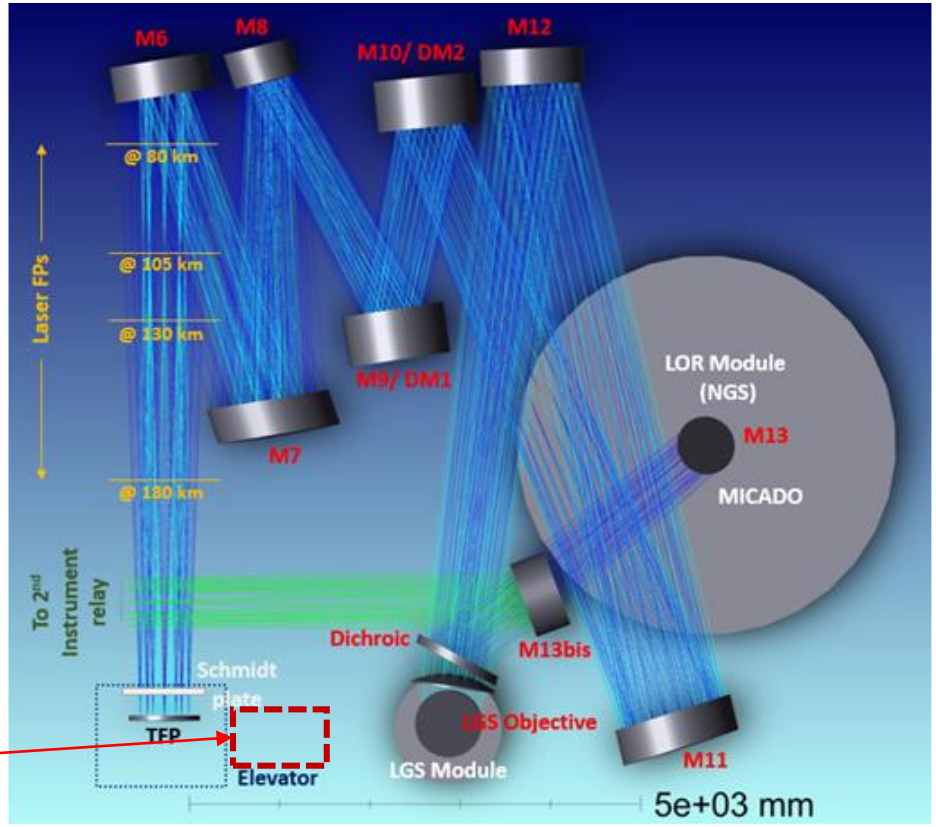
- ❖ AO corrections over a 60” FoV
- ❖ ELT first light instrument

- 8 LGS WFSs (HO corr.)
- 3 NGS WFSs (LO corr. + ref.)
- 2 DMs (Φ≈1m)
- λ range: [0.8 ÷ 2.4] um

Correction performance

- ➢ DL FoV (SCAO) → SR > 70%
- ➢ 1’ FoV (MCAO) → SR = 50% (goal) K-band





Calibrations

Calibration → Procedures to remove the instrumental signature from the scientific data

SCIENCE calibrations
(during telescope setup and interval of observations)

MONITORING calibrations
(predictive and preventive maintenance, at a lower rate)

Inputs from all sub-systems → Calibration tech. spec. → Calibration plan

⇩

To be managed at system level

Calibrations in MAORY

- Functionalities check
- AO loop parameters calib.

AO Calibrations

Functionalities check

WFS characterization
- Linearity
- Dynamic range
- Faint and bright regimes
- Flatness
- Gain and RON

Pupil check
- Misregistration (motion)
- Rotation
- Illumination uniformity
- Sampling

Optical system check
- Overall transmission
- …

AO loop parameters

NCPA
- Static
- Quasi-static (ΔT)
- Dynamic (vibrations)

IM construction
- LGS only
- LO-Ref only (VIS)
- LO only (IR)
- Combined IM

AO Calibrations – Focus on MAORY WFSs

LGS WFSs calibrations

- Periodic health check
- Reference slopes (HO static NCPA)
- Slope response of each subaperture
- Measurement of unvignetted FoV
- Interaction Matrix
- Pupil position
- Verification and test of WFSing algorithms

NGS (LOR) WFSs calibrations

- Verification of ADC focal plane wobble and pupil run-out
- Field mapping of LOR acquisition stages
- Interaction Matrix of each active element (trombone for focus correction, pupil steering mirror)
- Verification and test of WFSing algorithms

CTU vs. TU

Two different sub-systems, but they walk in parallel…

CTU → Calibration and Test Unit

- ✓ Functionalities check
- ✓ Post-focal DMs IM construction
- ✓ NCPAs
- ❖ No alignment purposes

Telescope

INAF - OAAb

Constraints (TIGHT!):

- Mass and Volume
- Fluxes
- …

TU → Test and Verification Unit

- ✓ AO performances verification
- ✓ Software functionalities checks
- ✓ ….

AIV

University of Galway

No particular constraints at the moment…

CTU tasks and requirements

MAIN TASK

Providing proper light sources (well-known features) for AO calibrations

REQUIREMENTS

The CTU shall provide:

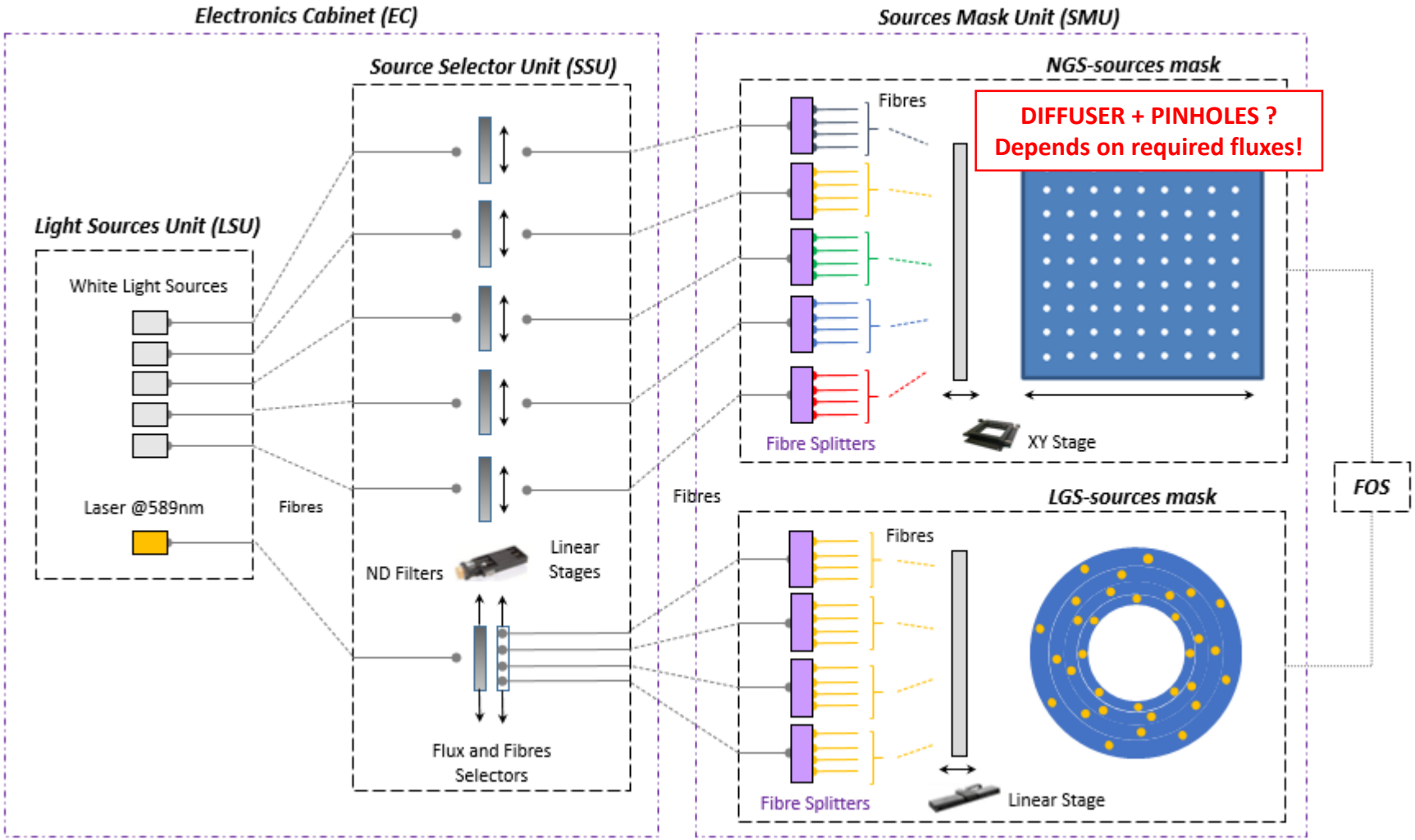
- A grid of 9x9 NGS sources
  - uniformly distributed within the NGS WFSs technical FoV (60")
  - sufficiently bright to cover the range 5-22 mag (TBC)
  - DL in H-band
- A set of LGS extended (3") sources
  - distributed on 4 asterisms with pupil rotation (0°, 30°, 42°, 56°)
  - asterisms conjugated with specific altitudes (160 km, 120 km, 104 km, 80 km)
  - 8 sources for each asterism
  - 589 nm wavelength
- The possibility to use at the same time both NGS and LGS sources.

…obviously while meeting the opto-mechanical constraints.

CTU Calibration sources overview

Type	Use	λ	Size	SR	Flux range [phot/s]	Mags range
NGS	**LOR wfs (Ref.)**	**R band**	**≤ 4 mas (DL@R)**	**> 85%**	**$2 \cdot 10^4 \div 1 \cdot 10^{11}$**	**5 ÷ 22**
NGS	LOR wfs (LO)	I band	≤ 5 mas (DL@I)	> 85%	$1 \cdot 10^4 \div 8 \cdot 10^{10}$	5 ÷ 22
NGS	LOR wfs (LO)	J band	≤ 8 mas (DL@J)	> 85%	$7 \cdot 10^3 \div 5 \cdot 10^{10}$	5 ÷ 22
NGS	**LOR wfs (LO)**	**H band**	**≤ 10 mas (DL@H)**	**> 85%**	**$5 \cdot 10^3 \div 3 \cdot 10^{10}$**	**5 ÷ 22**
LGS	**LGS wfs (HO)**	**589 nm (V band)**	**3”**	**-**	**$5 \cdot 10^8 \div 5 \cdot 10^{10}$**	**6 ÷ 11**

CTU Architecture



CTU Opto-mechanics

SMU

Source Mask Unit | Composed by two separated sources masks:

- NGS and LGS masks not aligned (shorter axial size) → All sources can be imaged together
- Need of a beam combiner (BC)

FOS

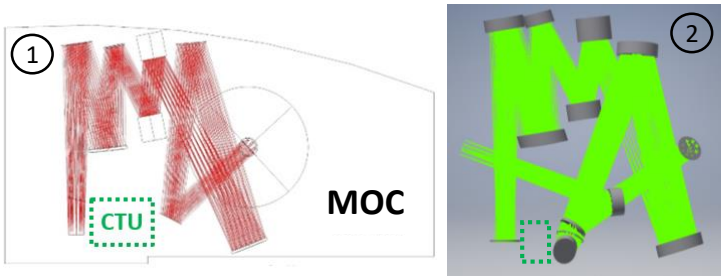
Focusing Optical System | To fulfill the optical requirements (f-number, pupil position, etc.)

BM

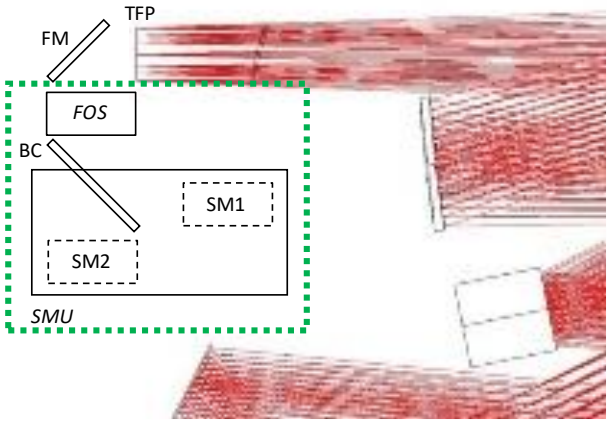
Beam combiner | To simultaneously image both NGS and LGS sources.

FM

Folding Mirror | Into the elevator, to inject the flux into the telescope light path.



CTU volume strictly depends on MAORY optical design!



Focusing Optical System (FOS)

Optical constraints

- Match ELT f-numbers (17.7 @inf. ÷ 20.9 @80km)
- Match ELT FP curvature radii (-9884mm @inf. ÷ -9170mm @80km)
- NGS light sources DL on TFP
- LGS light sources extended (3”) on LFPs
- Create a single pupil in the nominal position (-37868mm @inf. ÷ -44782 @80km)

Mechanical constraints

- Axial size: 2 meters as total length (TBC)

CONCEPT

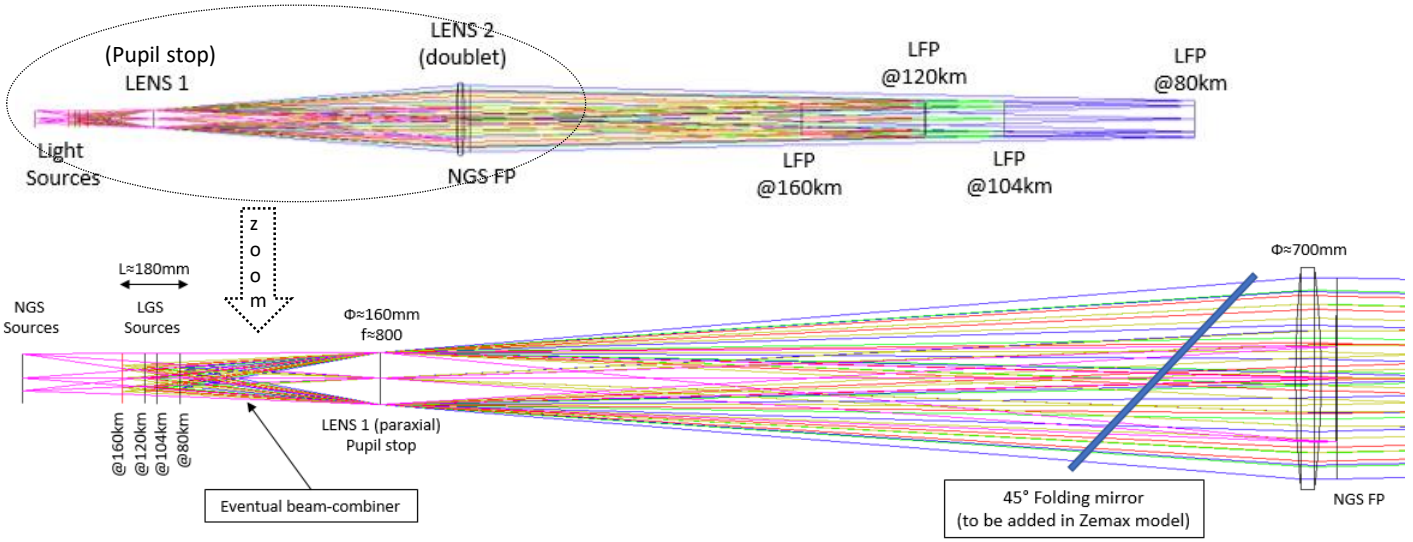
LENS 1 (paraxial) | Objective and pupil stop → Provides the proper f-numbers
LENS 2 (real) | Field lens → Provides the proper pupil positions

Merit function operands
- Radial position of sources on FPs
- F-numbers
- Pupil positions

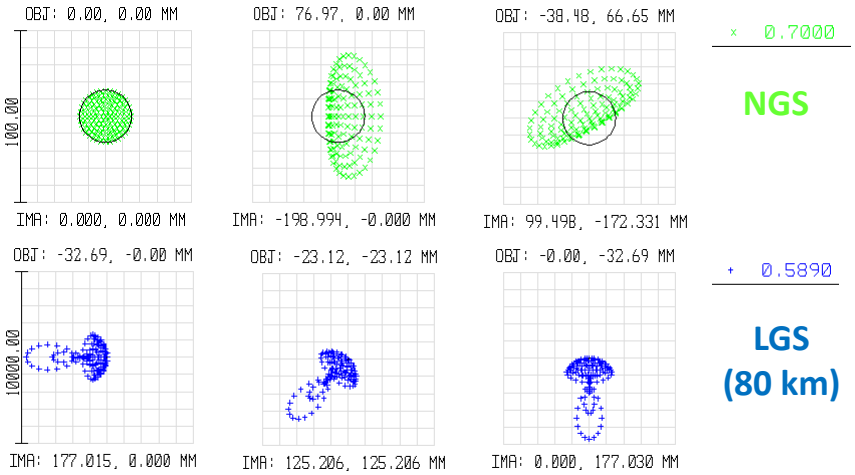
Optimization outputs
- Axial position of LENS 1
- Axial position of sources masks
- Radial position of sources on masks

Focusing Optical System (FOS)

Guess 1
(no constraints on size)

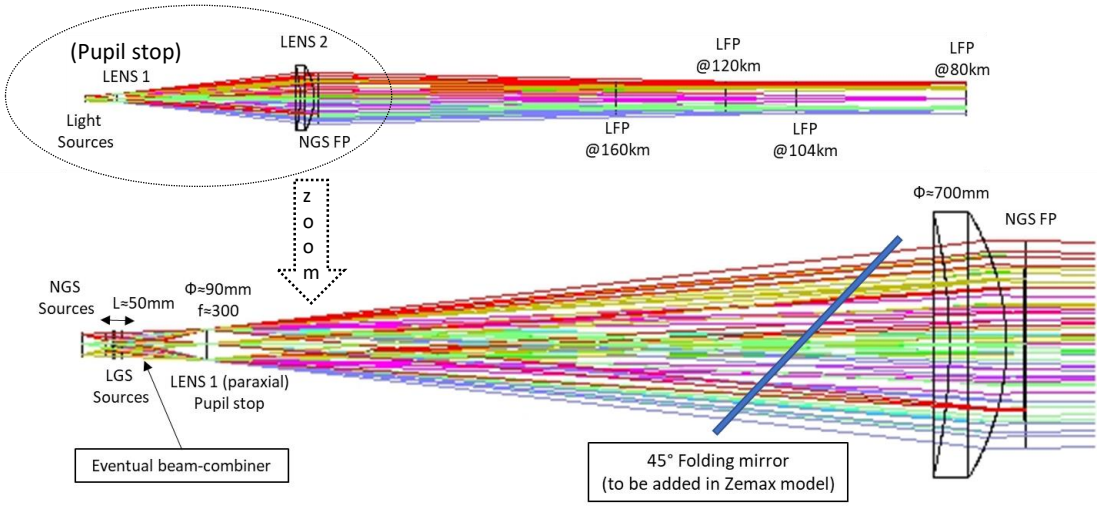


- ✓ **Quality NGS → OK (DL on-axis)**
- × **Quality LGS → NOK**
- ✓ **F-numbers → OK (Δ<1%)**
- ✓ **Pupil position → OK**
- ✓ **FP curvature radii → OK**
- ✓ **Sources position on FPs → OK (Δ<3%)**
- × **Axial length: 4,2 m → NOK (too long)**

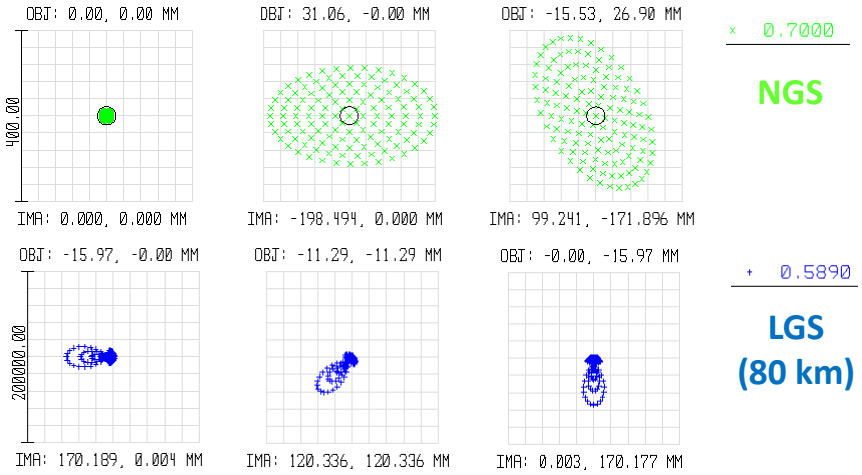


Focusing Optical System (FOS)

Guess 2
(constraints on size forced in the merit function)

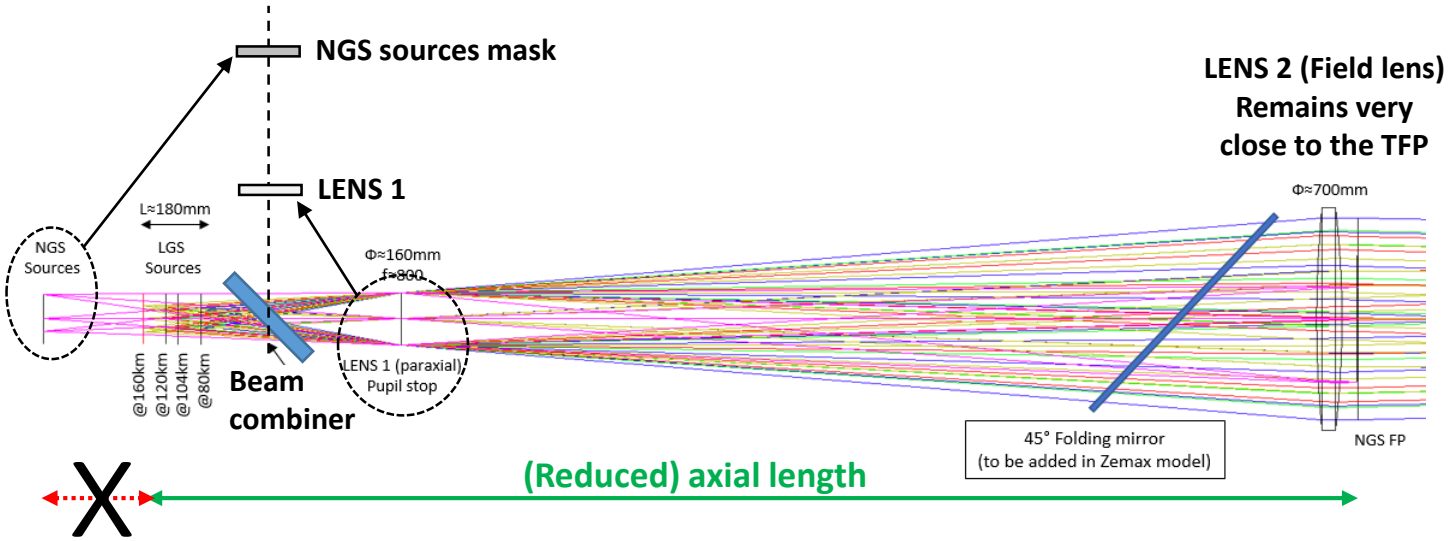


- ✓ Quality NGS → OK (DL on-axis)
- × Quality LGS → NOK
- × F-numbers → NOK (Δ≈30%)
- ✓ Pupil position → OK
- ✓ FP curvature radii → OK
- × Sources position on FPs → NOK (Δ≈10%)
- ✓ Axial length: 2,5 m → OK



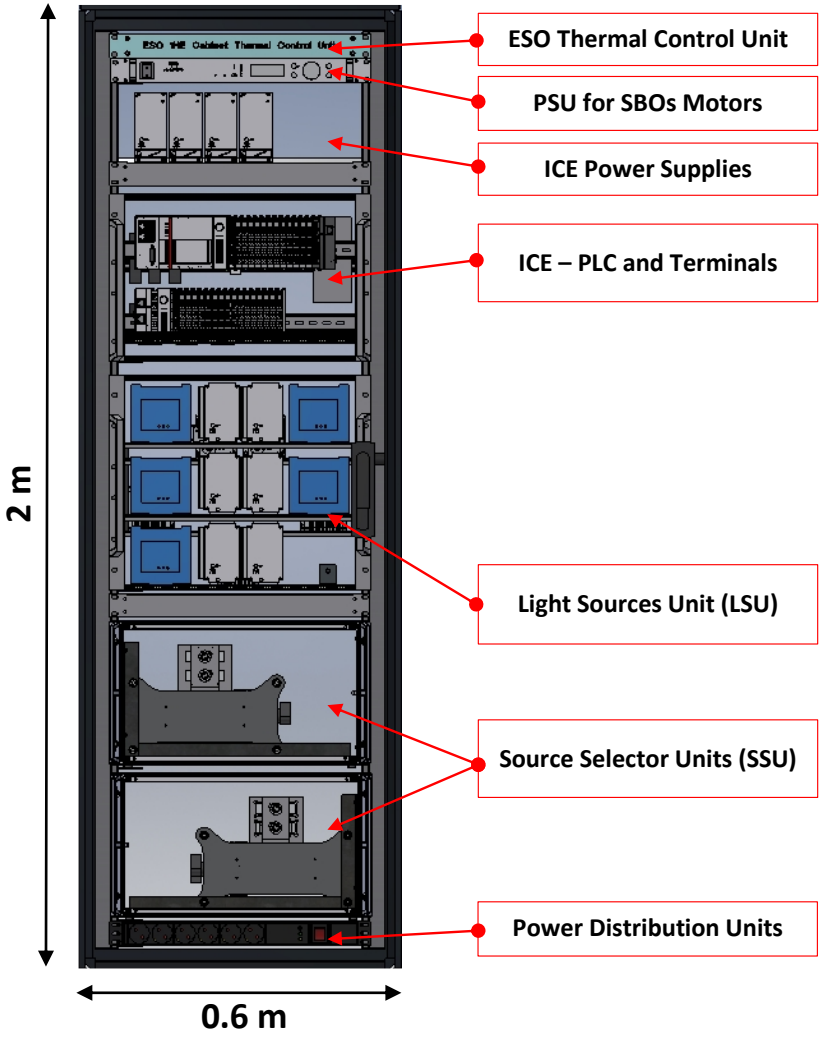
Focusing Optical System (FOS)

Guess 3



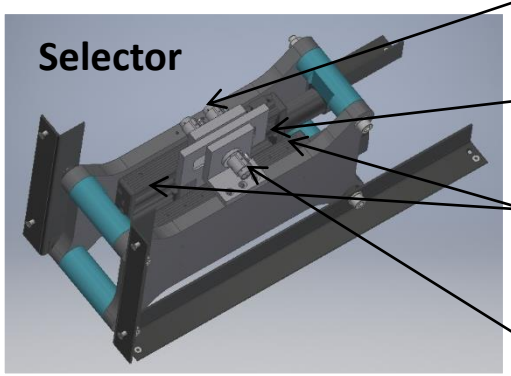
…coming soon…

CTU Electronics Cabinet



LSU

SSU



Road to PDR

Steps done

- ✓ Defined CTU concept (Architecture)
- ✓ Started (draft of) optical design
- ✓ Started (draft of) mechanical design
- ✓ Started (draft of) electronic design
- ✓ Found COTS
- ✓ Started contacts with companies

Design Approach → *Flexibility*

1) Define the paraxial configuration of the optical system
2) Turn the lenses from paraxial to real
3) Fold the optical design into a reasonable volume
4) Build the mechanics around this optical design
5) Check if CTU design is compatible with MAORY optical design:
   - YES → go on
   - NO → back to (1)

Next steps

- ➢ Optimization of optical model
- ➢ Optimization of mechanical model
- ➢ Starting prototyping and test activities for the whole transmission chain (physical sources, fibre splitters, fibres)
- ➢ Designing the test apparatus (for the future AIV phase)

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THANKS FOR YOUR ATTENTION

Ivan Di Antonio ivan.diantonio@inaf.it

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Some data from ELT…

Altitude [km]	Focal plane position [mm]	F-number	Scale [mm/arcsec]	Exit Pupil position (from FP) [mm]	FP Curv. Radius [mm]
80	6916	20.98	3.920	44782	-9170
104	5104	20.13	3.763	42972	-9303
120	4345	19.78	3.696	42213	-9391
160	3168	19.23	3.593	41036	-9507
inf	0	17.74	3.316	37868	-9884

WFS calibration details

- Verification and test of LGS WFSing algorithms:
  - Verification of RTC centroid computation (output slopes) with respect to computation performed offline based on pixel intensity vectors. Regression test (with camera simulator?);
  - Test of detector dark follower algorithm, keeping track of the offset drifts in dark areas;
  - Test of LGS WFS spot monitor algorithm, fitting the spot shape and providing elliptical fwhm for trending;
  - Test of under-illumination alarm, which freezes the loop when a TBD number of subap. exhibit less flux than the median flux over the subap divided by a TBD value.

- Verification and test of LOR WFSing algorithms:
  - Verification of RTC centroid computation (output slopes) with respect to computation performed offline based on pixel intensity vectors;
  - Test of background follower algorithm, keeping track of the background offset away from the PSF core;
  - Test of NGS WFS spot monitor algorithm, fitting the spot shape and providing elliptical fwhm to generate weighting maps and for trending;
  - Test of under-illumination alarm.