MAORY Presentation

6-7 / 02 / 2020

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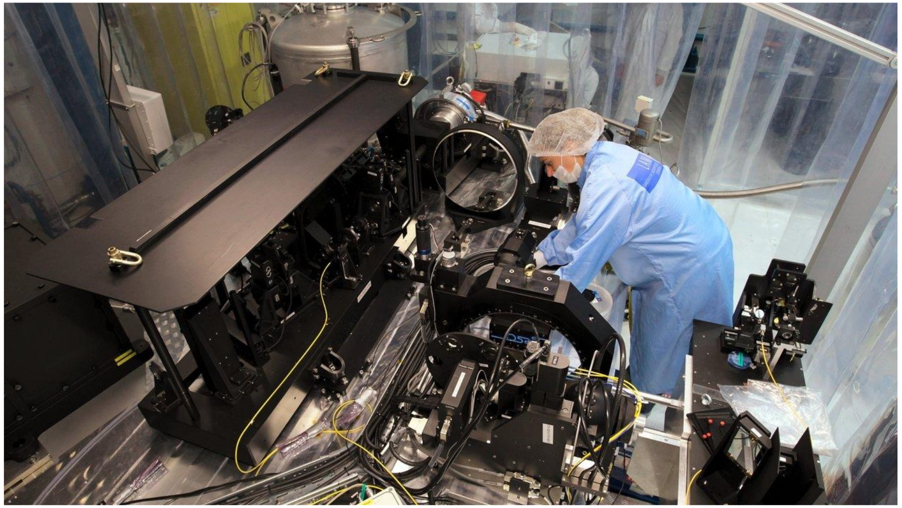
MPIA – MAORY Presentation

- MCAO presentation
- MAORY optical design history
- LGS-WFS module

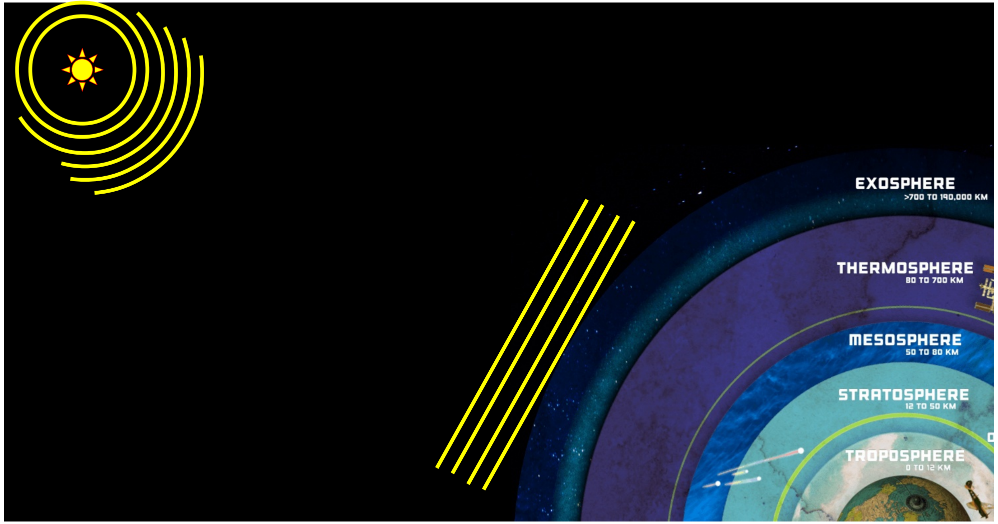
What is MCAO ?

- Adaptive Optics: a little history
  - First civil use: prototype COME-ON, end-of the 80’
  - First scientific instrument: ADONIS @ ESO LaSilla in 1991
  - NAOS – CONICA @ VLT: First light in 2001, decommissioned on 1st October 2019
  - SPHERE @VLT in 2014
  - 4×CIAO @VLTI in 2016
  - MICADO @ELT in 202?



What is MCAO ?

- Adaptive Optics: what is it ?



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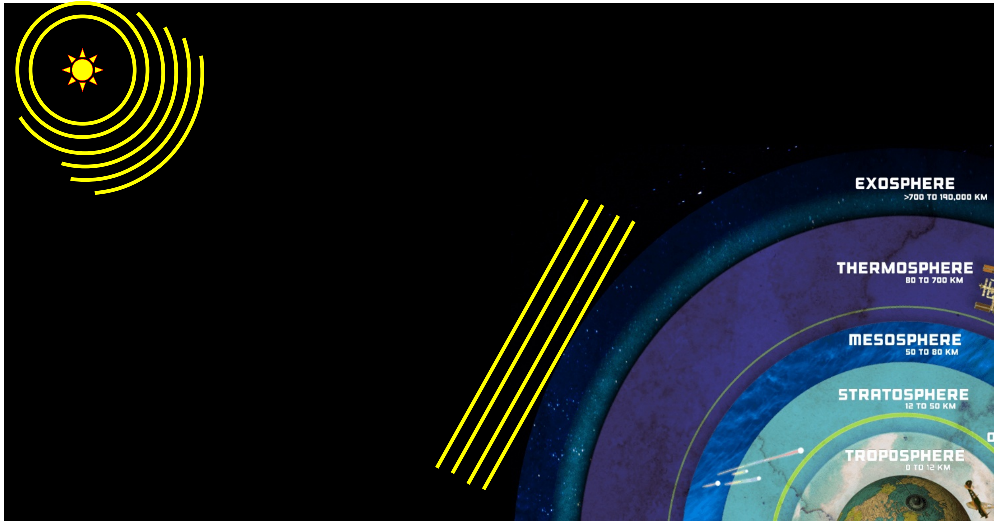
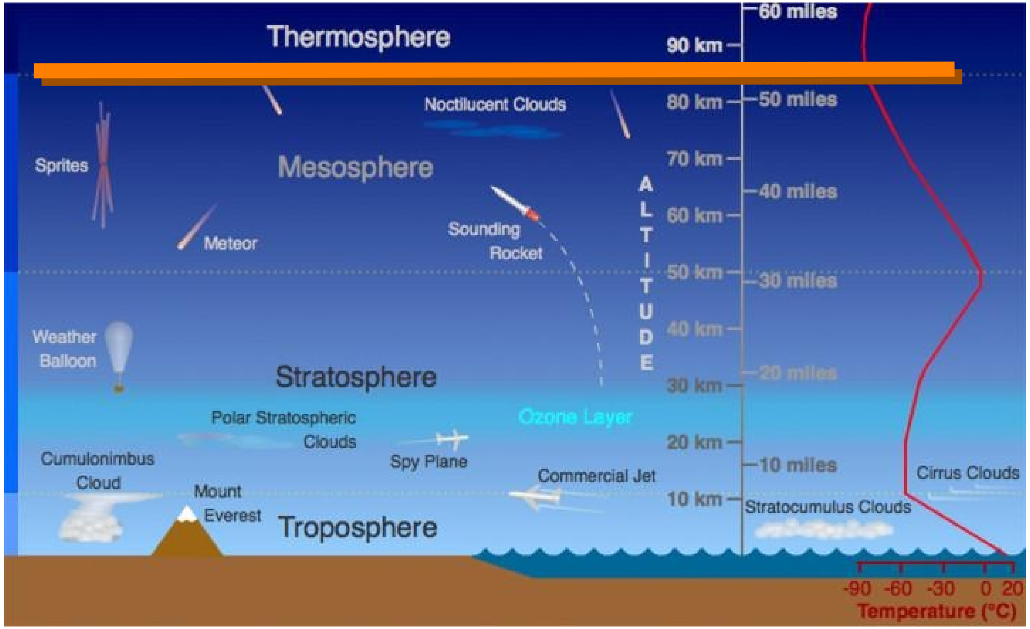


Von Kármán limit: 100km
Sodium layer: 85km



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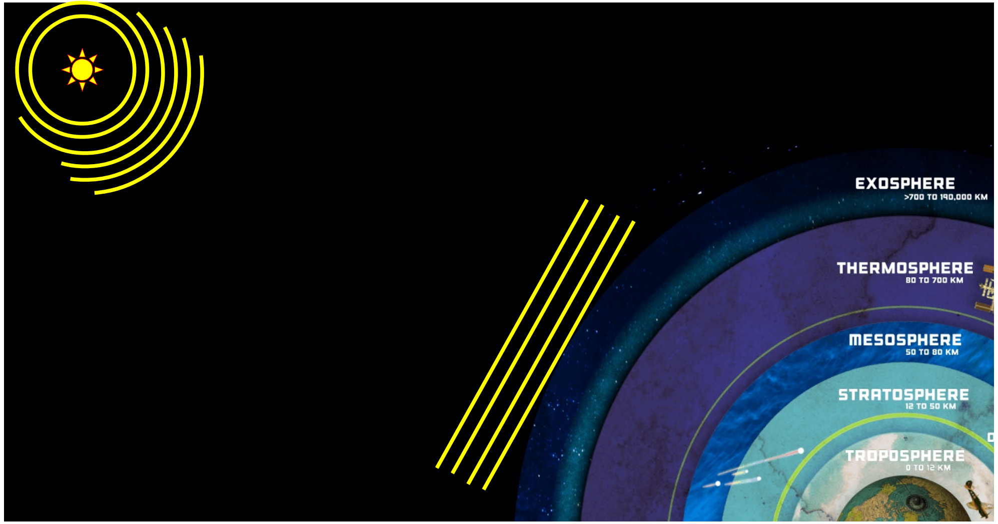
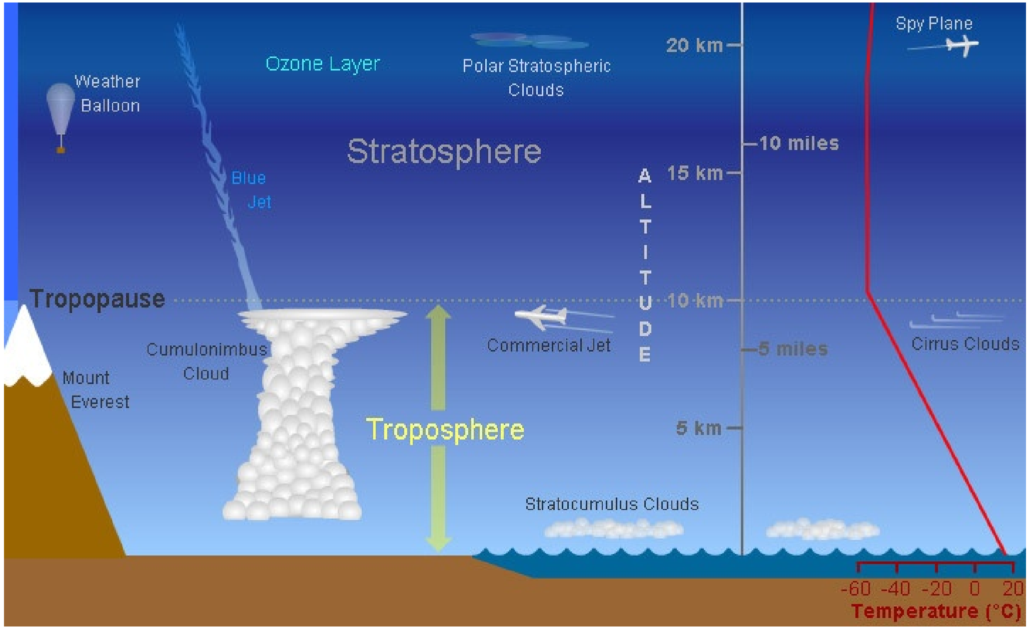


Refraction index of air is T° and P dependent



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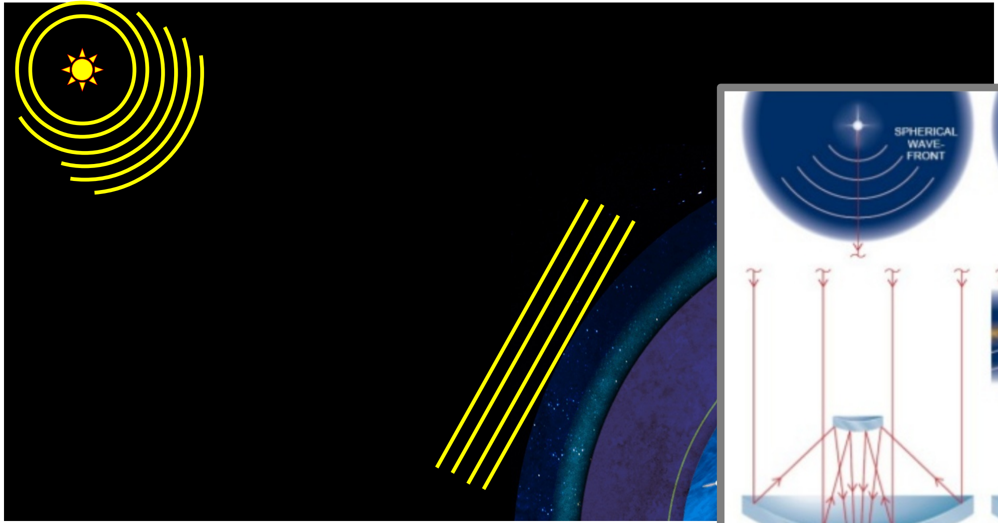

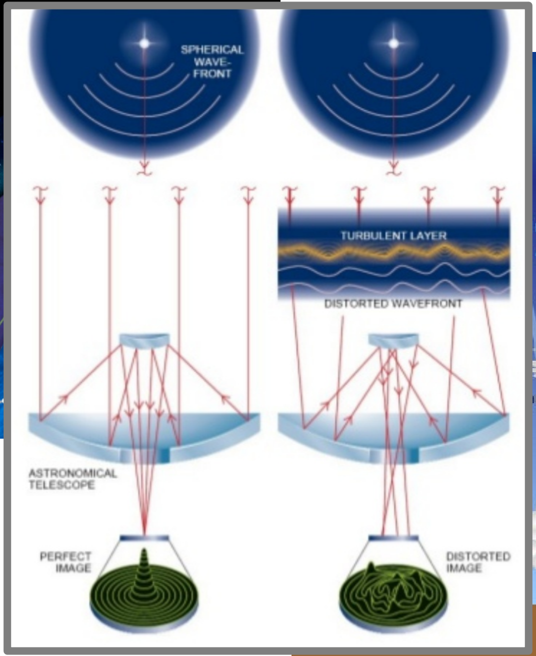

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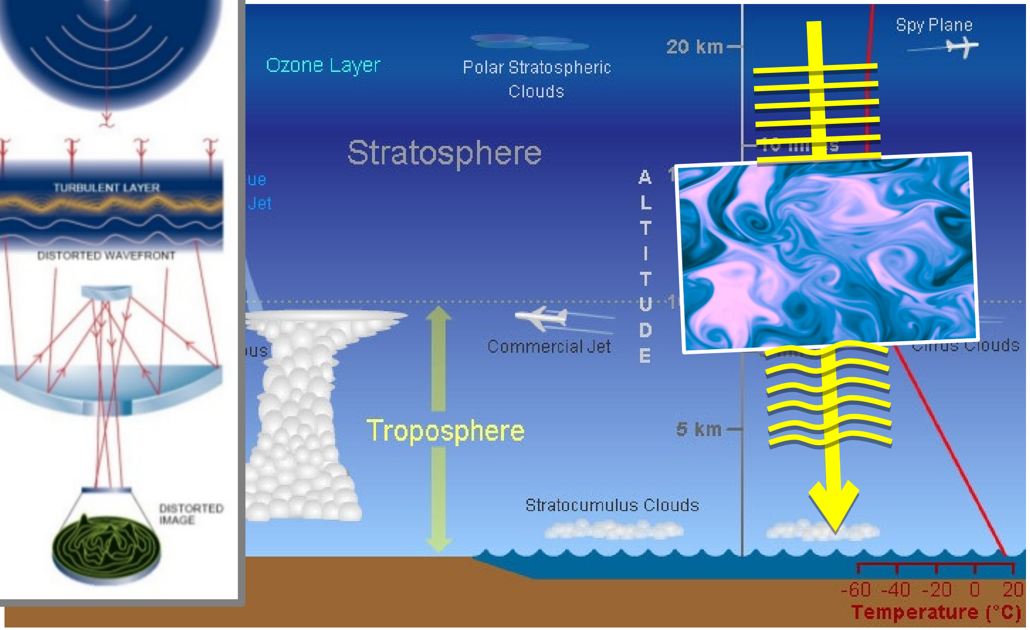
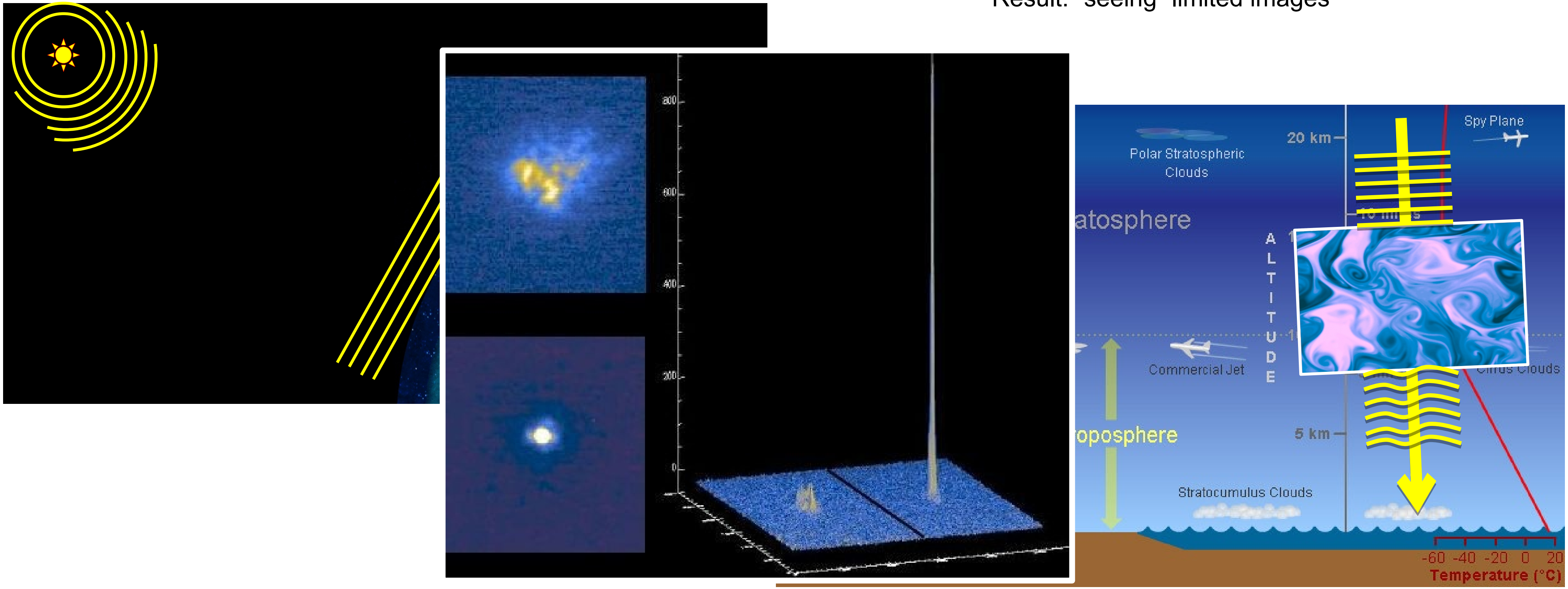


What is MCAO ?

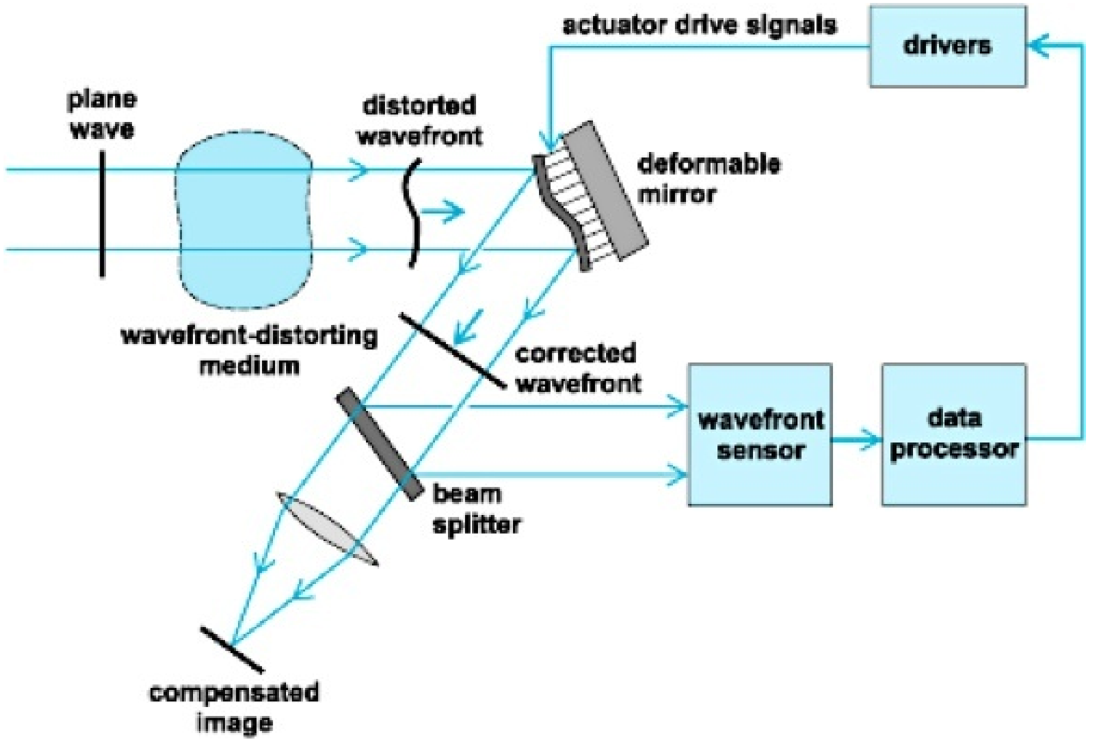
- Adaptive Optics: what is it ?

Result: “seeing” limited images



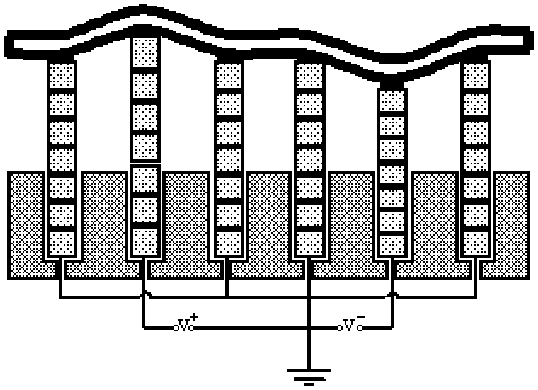
What is MCAO ?

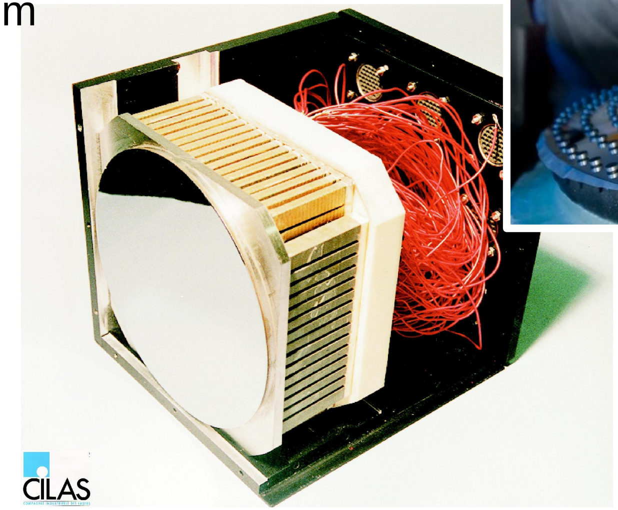
- Adaptive Optics:
  - Schematics

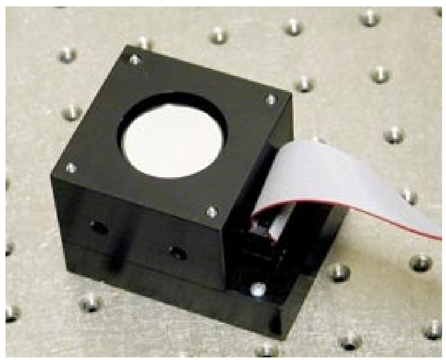


What is MCAO ?

- Adaptive Optics:
  - Schematics
  - Deformable mirror:
    - from Ø10mm to Ø1m
    - Flat or powered

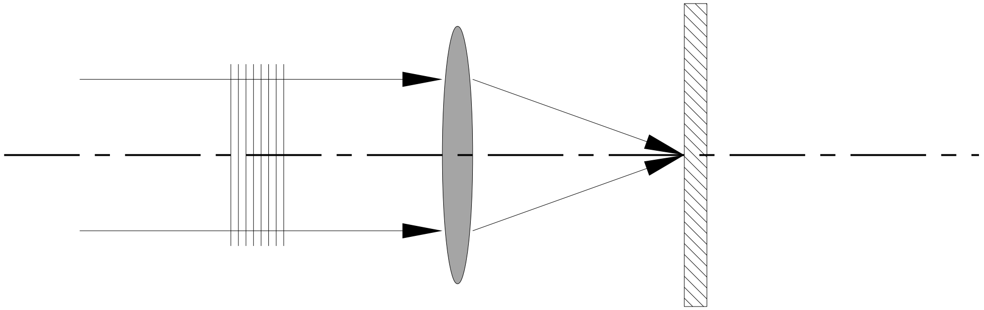






What is MCAO ?

- Adaptive Optics:
  - Schematics
  - Deformable mirror
  - Wave-front sensor: Shack-Hartmann



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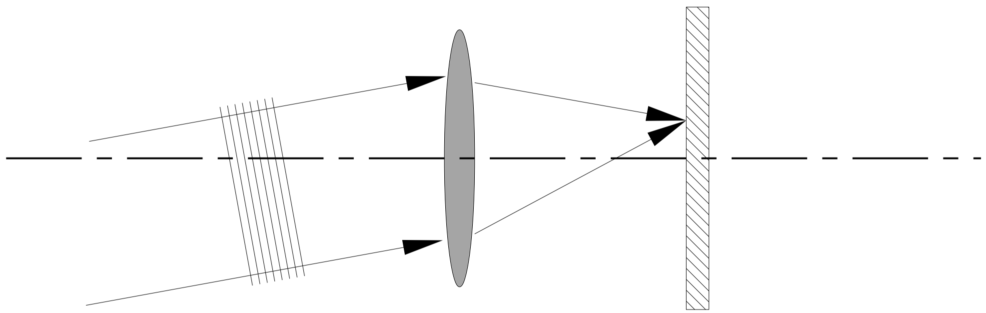

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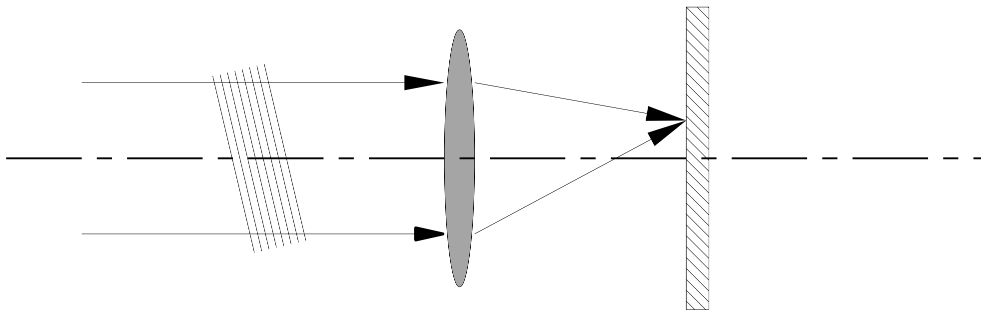

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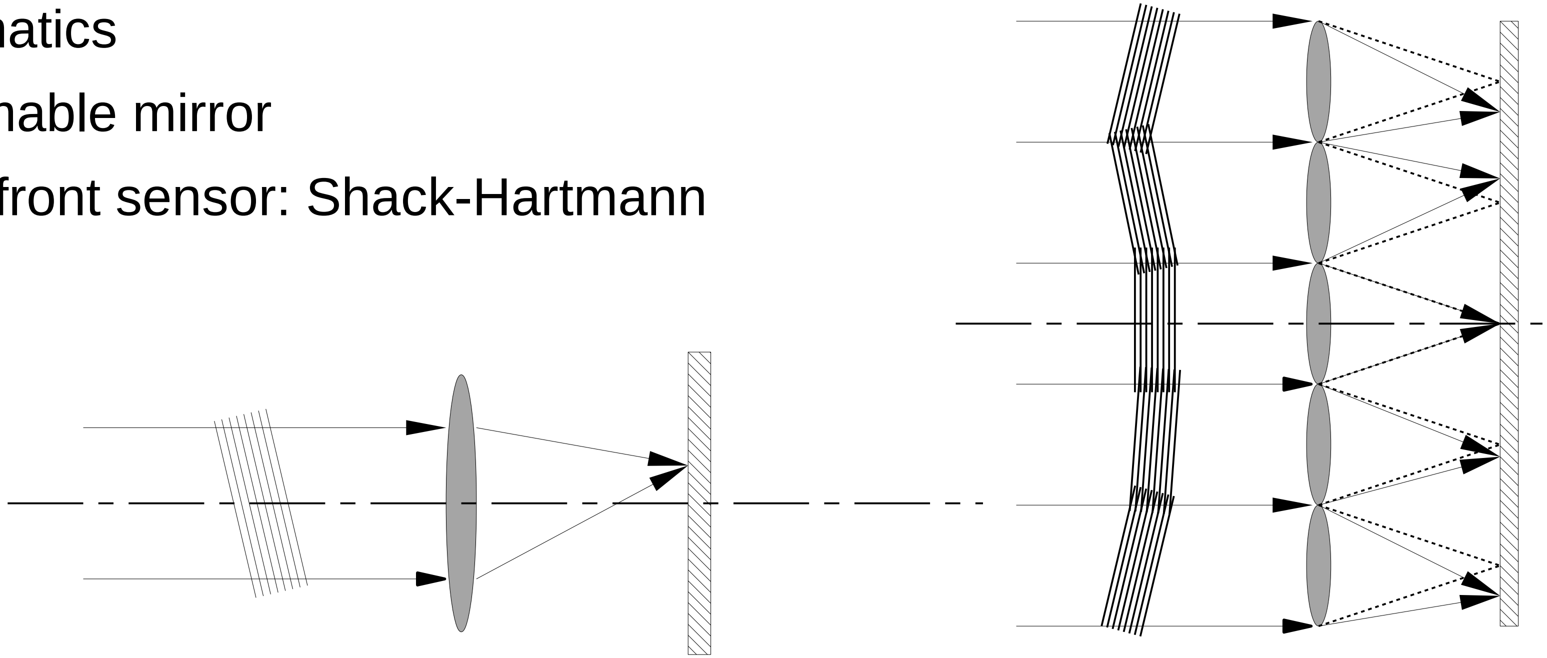

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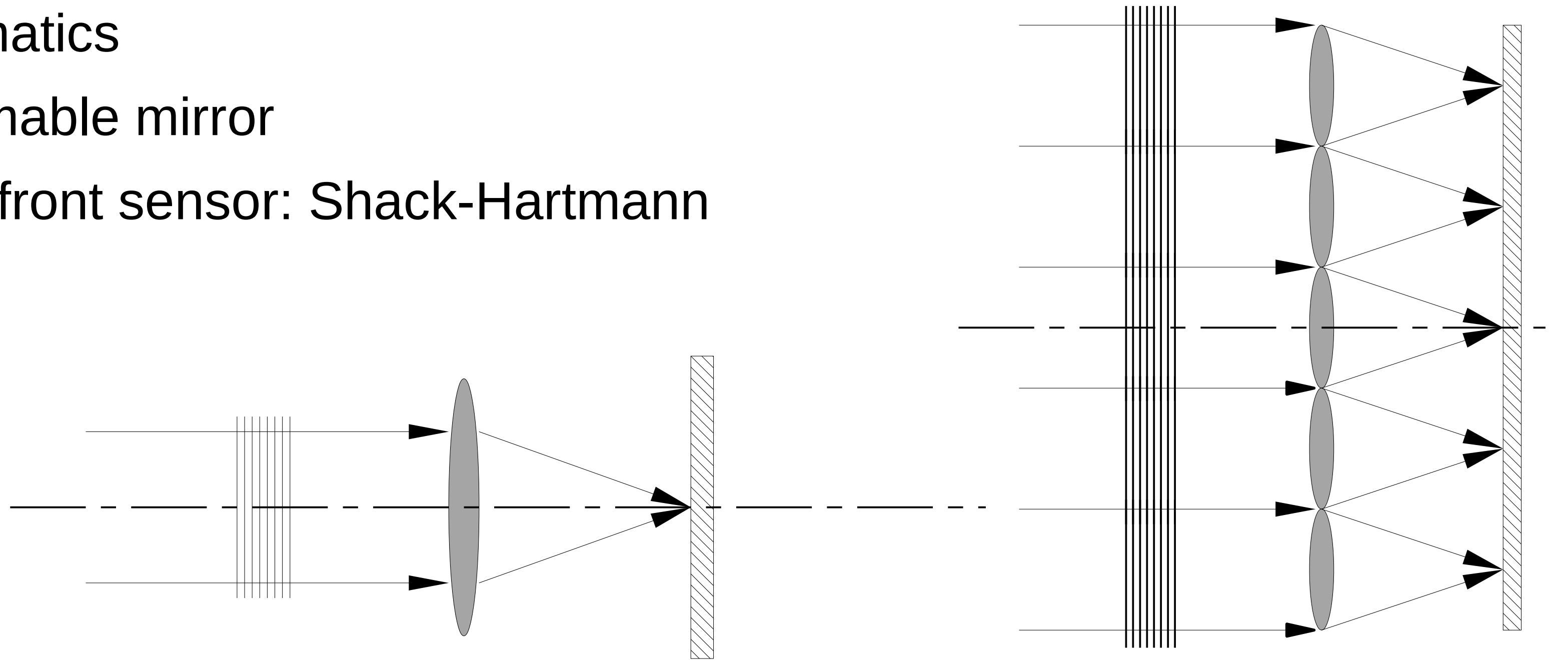

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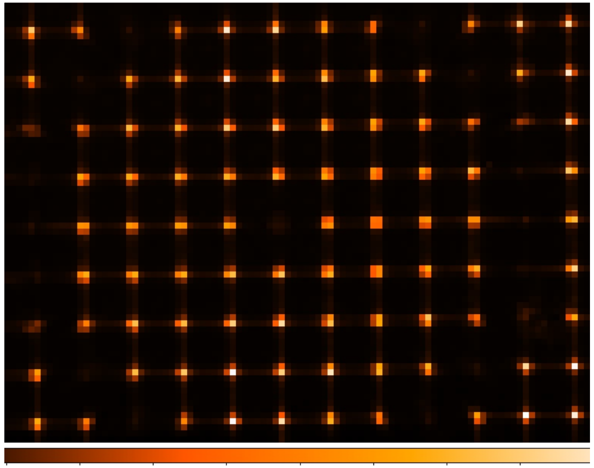

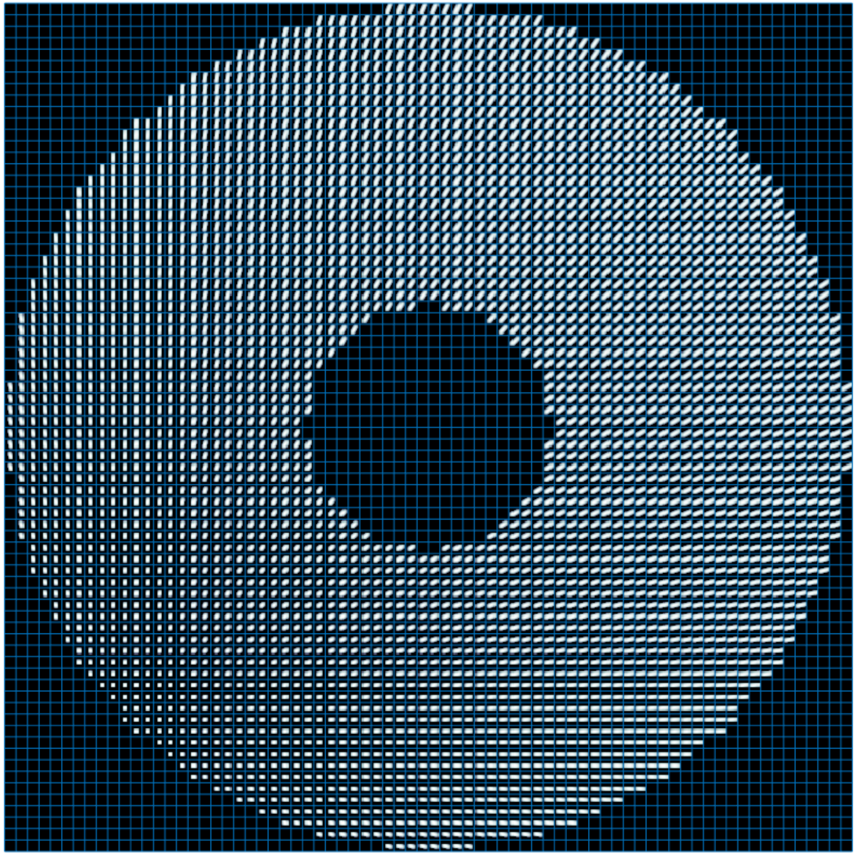

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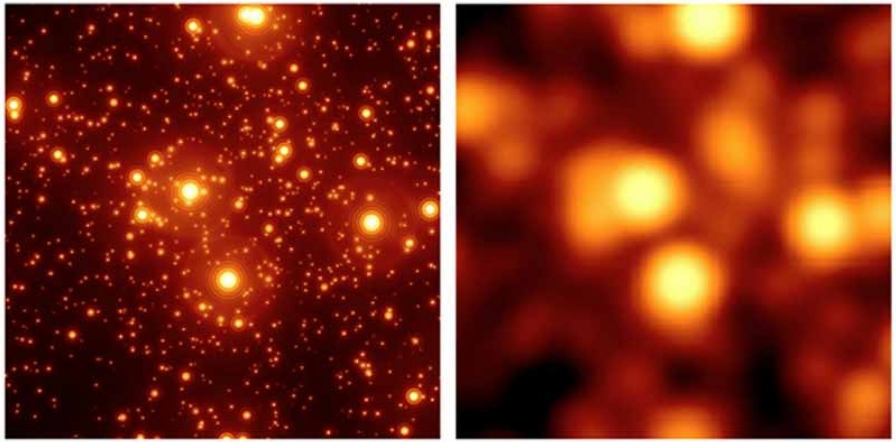
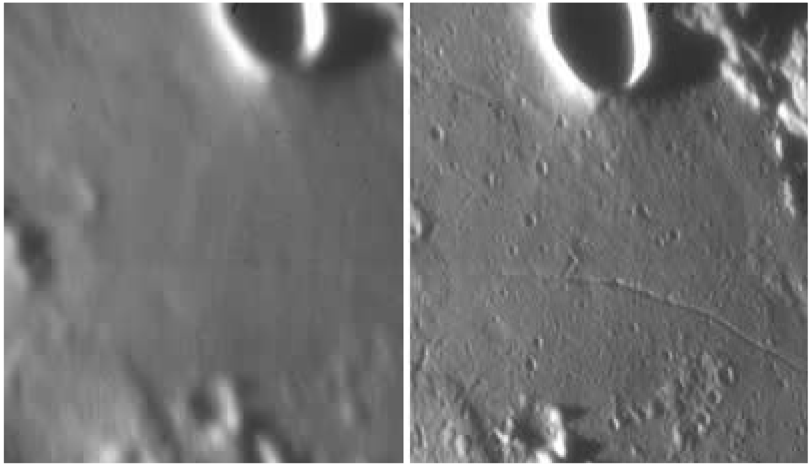
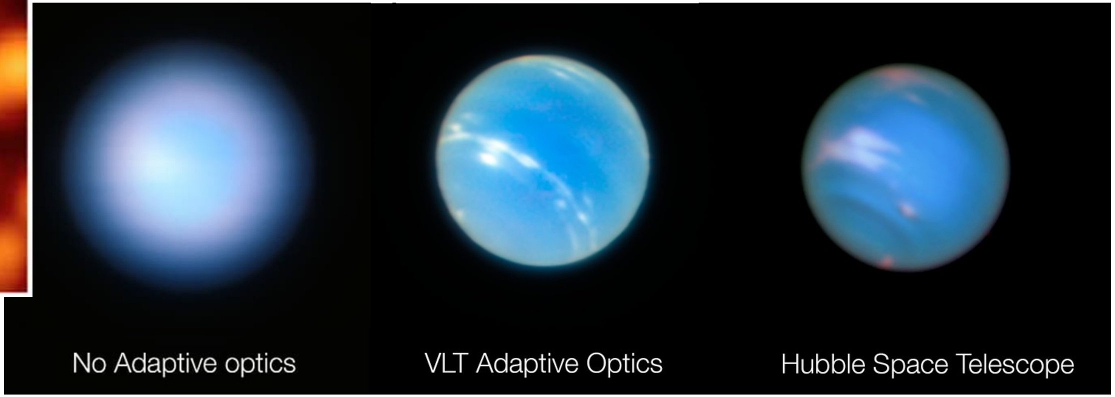
- Adaptive Optics:
  - Now a proven technique







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- Adaptive Optics:
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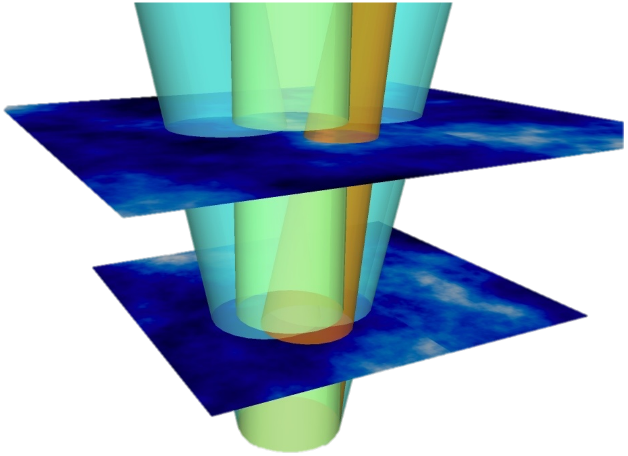
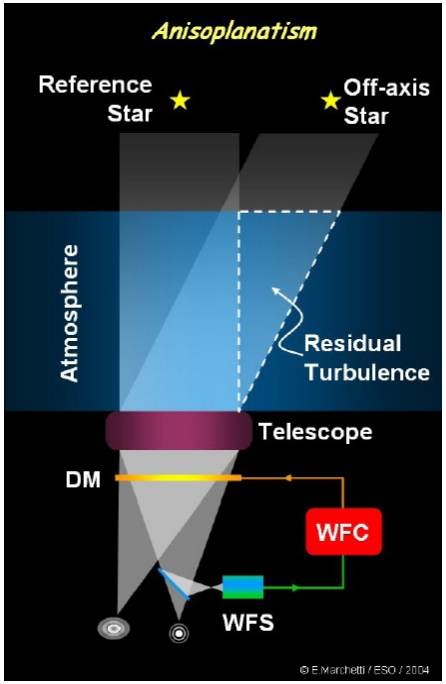
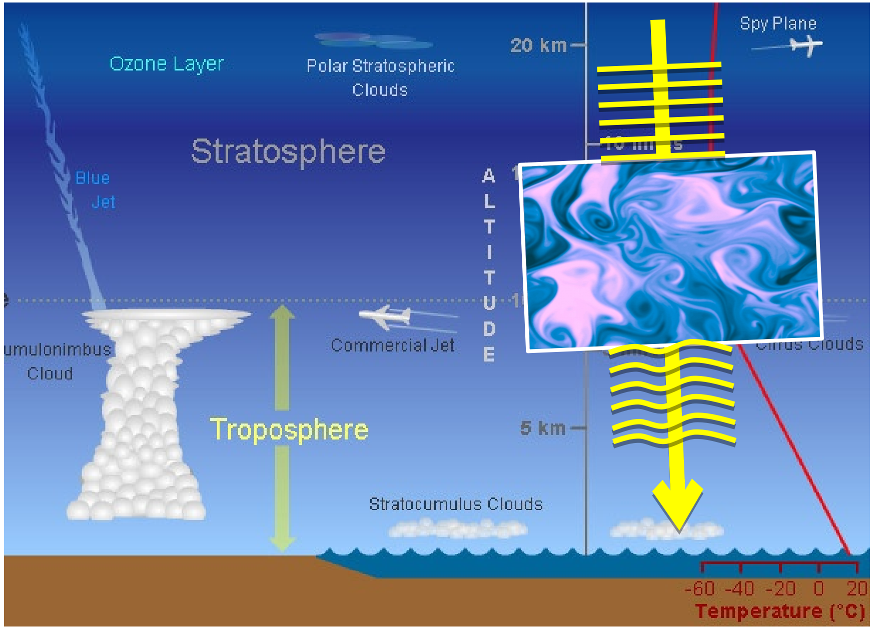
  - Why MCAO ?
  - Anisoplanetism







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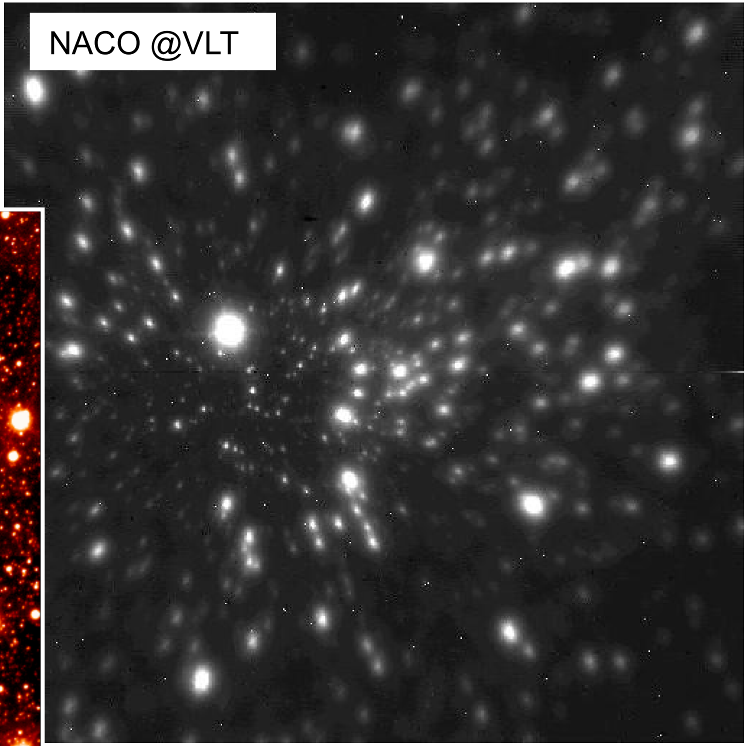

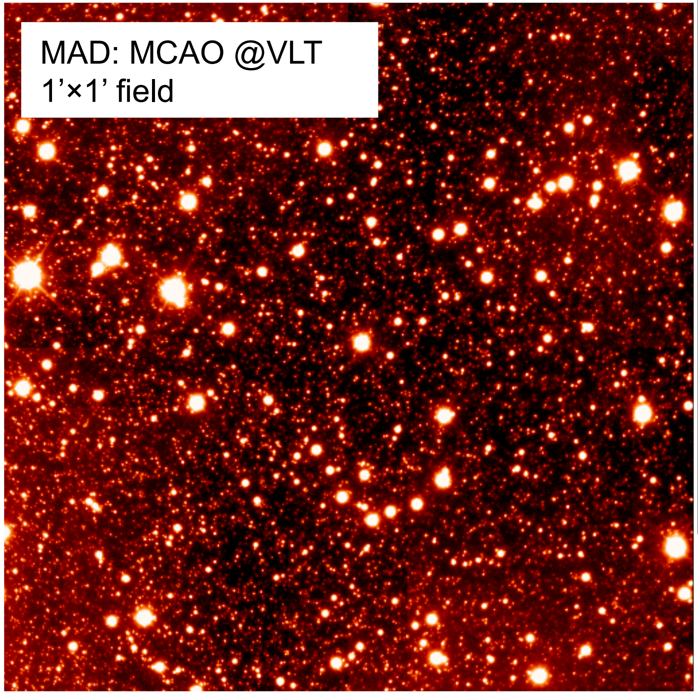

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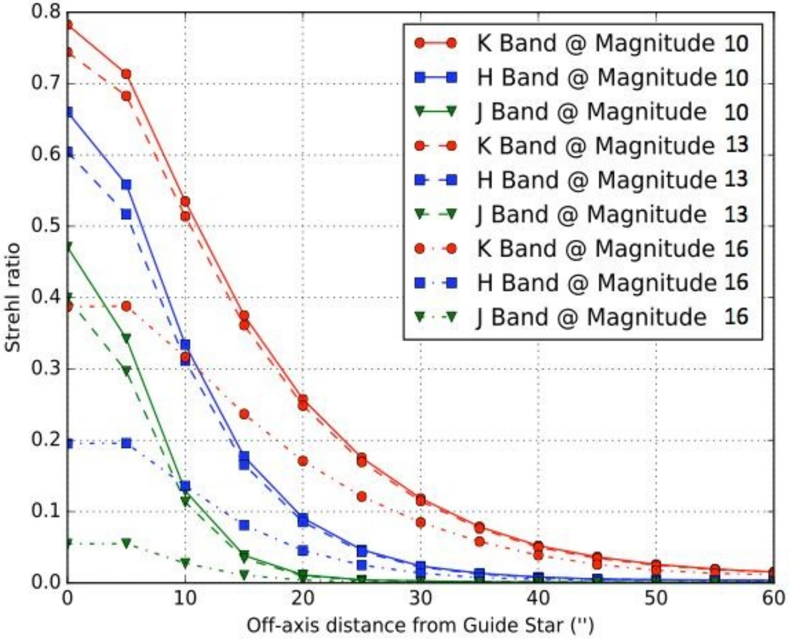

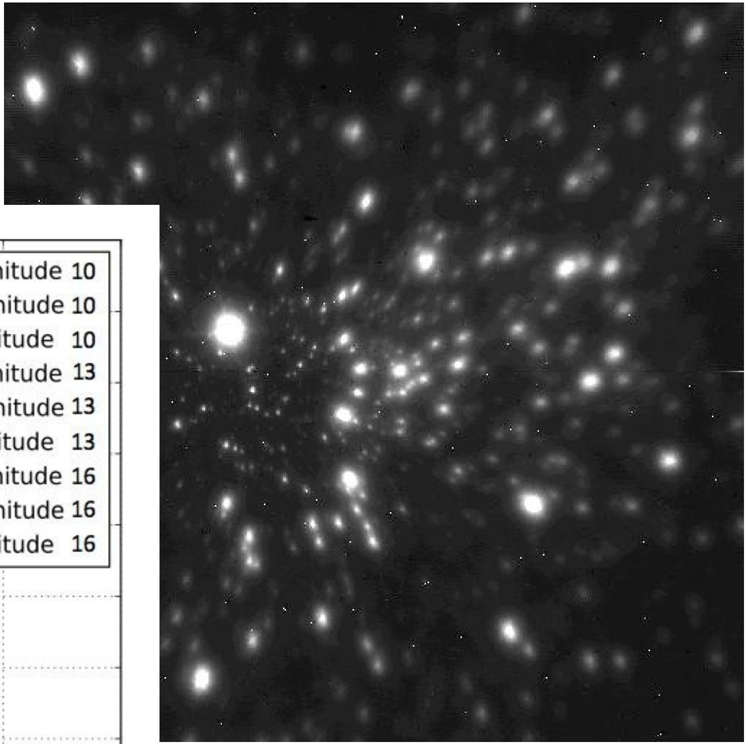

MICADO-SCAO @ELT
1’×1’ field

What is MCAO ?

- Adaptive Optics:
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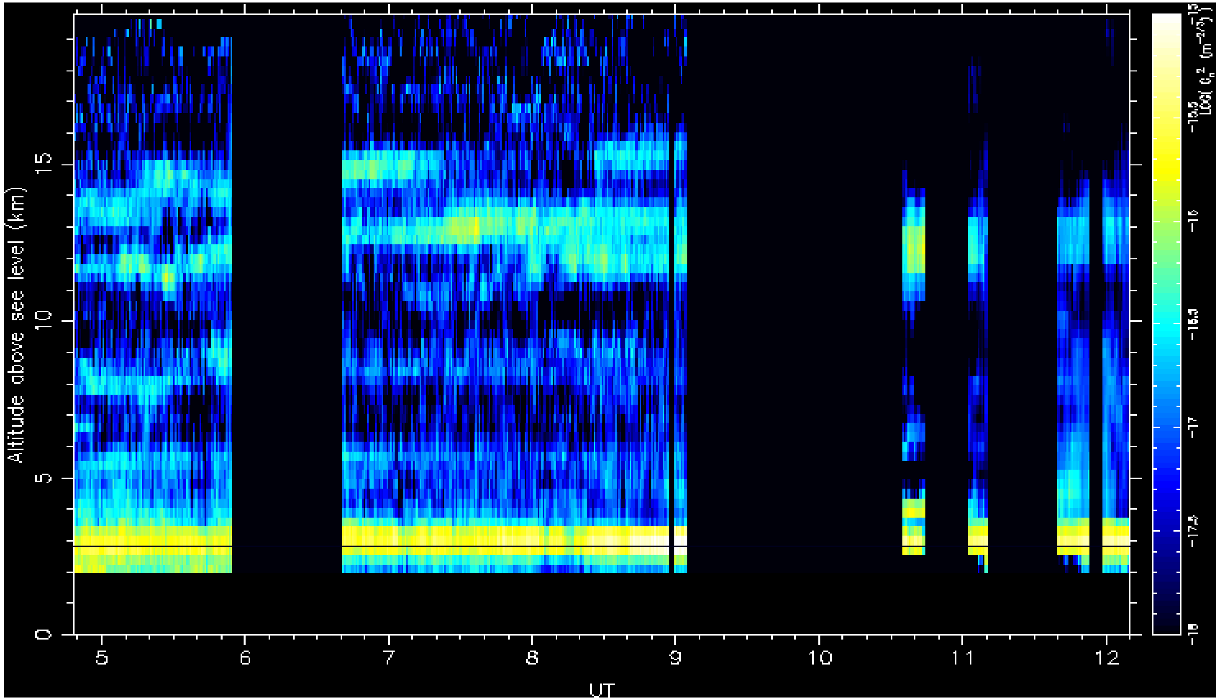
  - Anisoplanetism
  - Atmosphere turbulence is in layers



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- Adaptive Optics:
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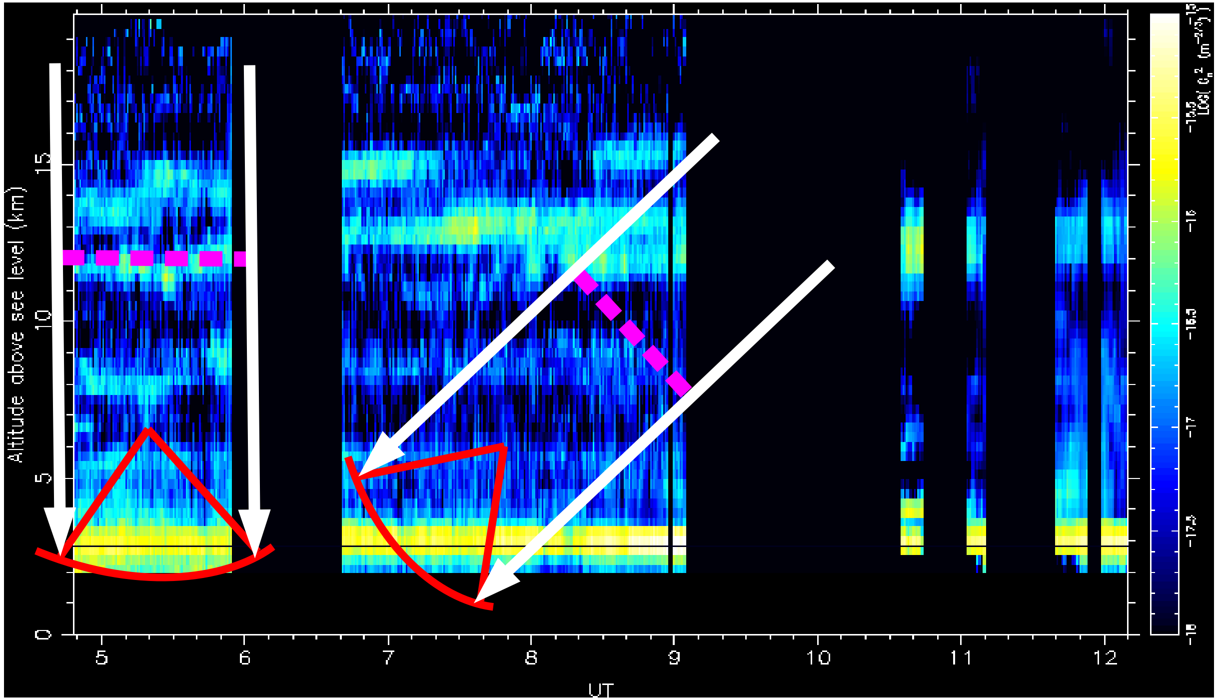
  - Anisoplanetism
  - Atmosphere turbulence is in layers
  - MCAO : conjugate DM on those layers

    → correct conjugation is a statistical choice



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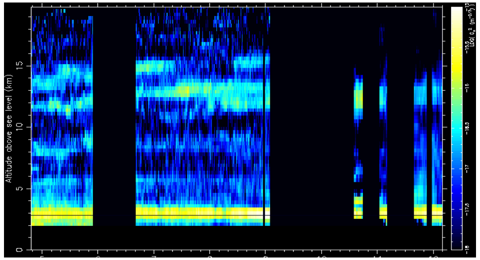

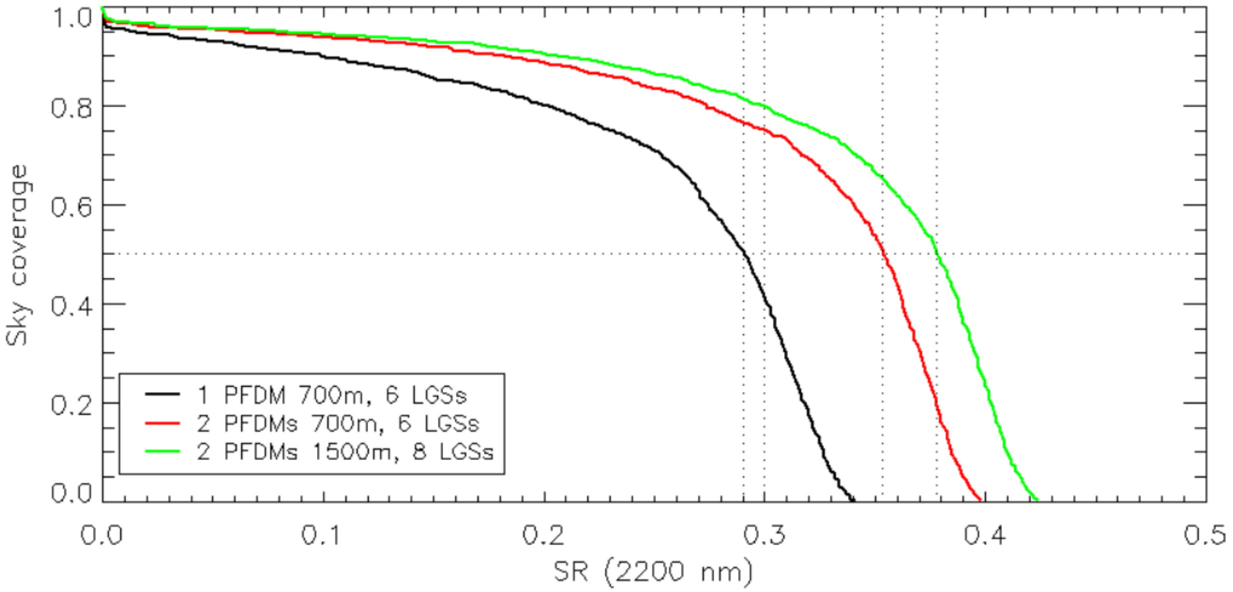

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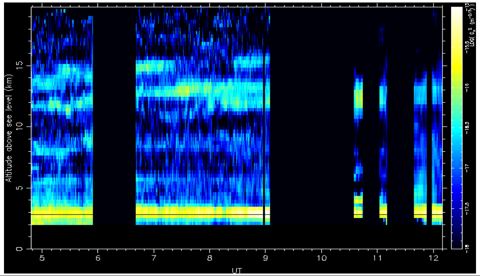

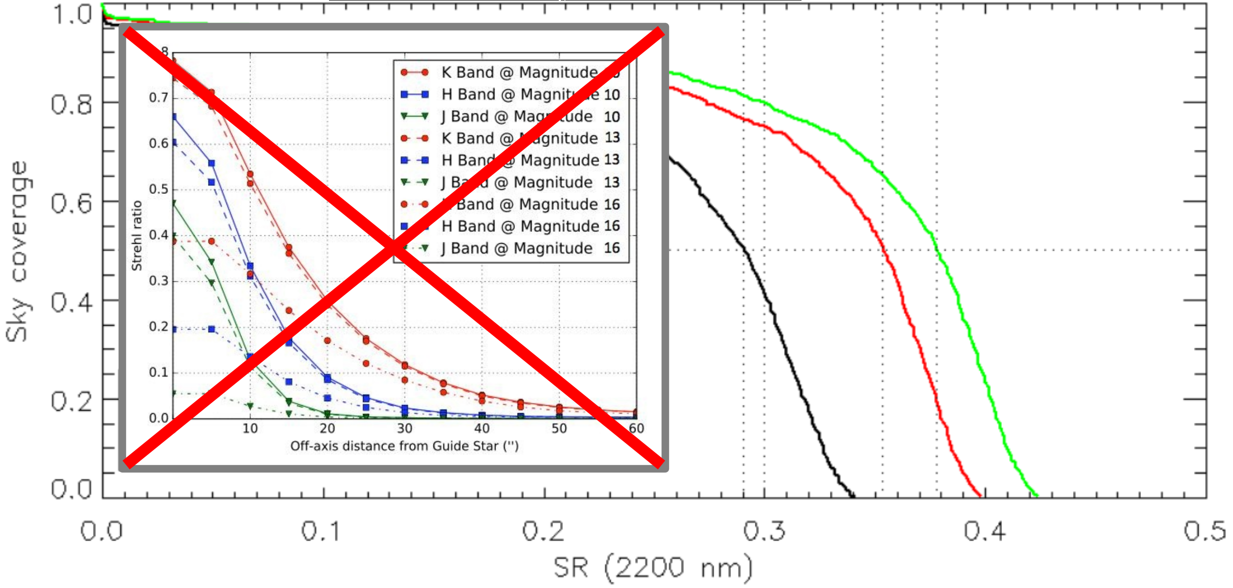

What is MCAO ?

- Adaptive Optics:
  - Why MCAO ?
  - Tomography :
    How to reconstruct
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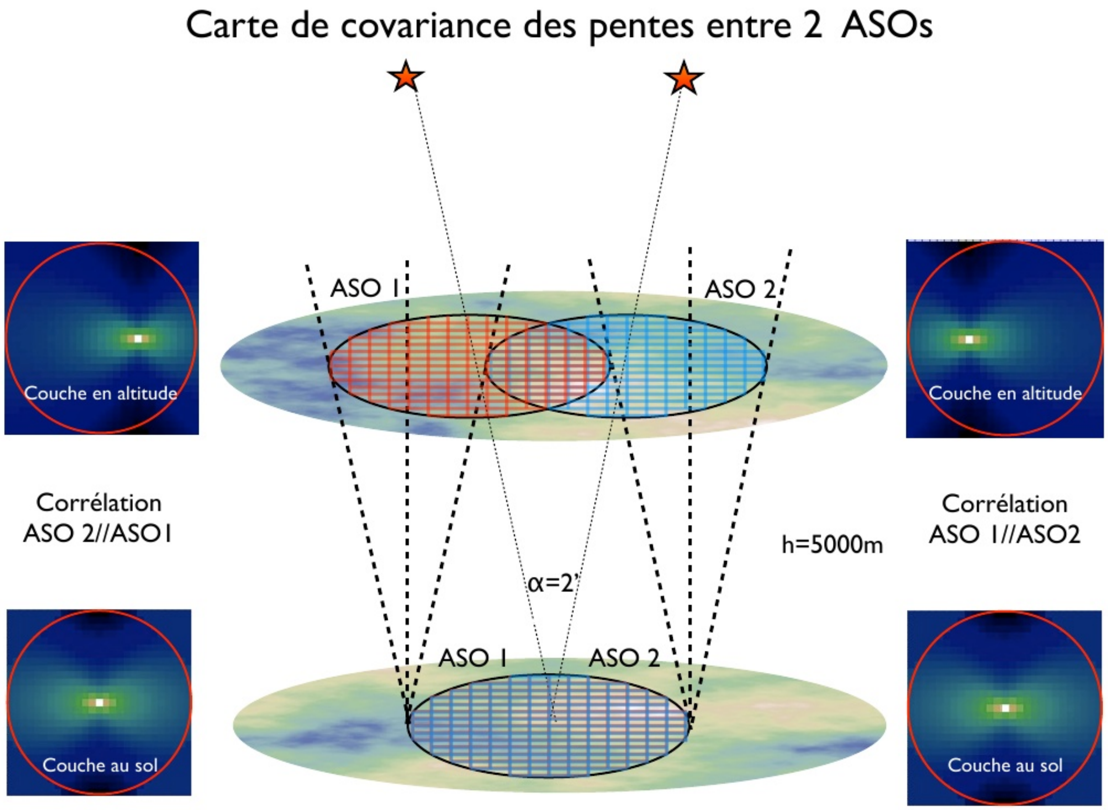
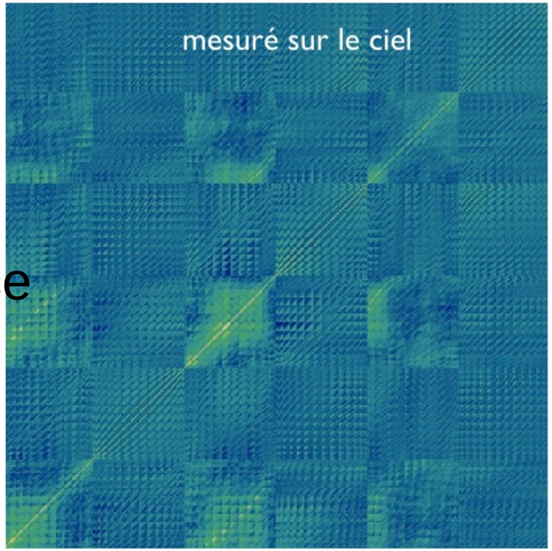
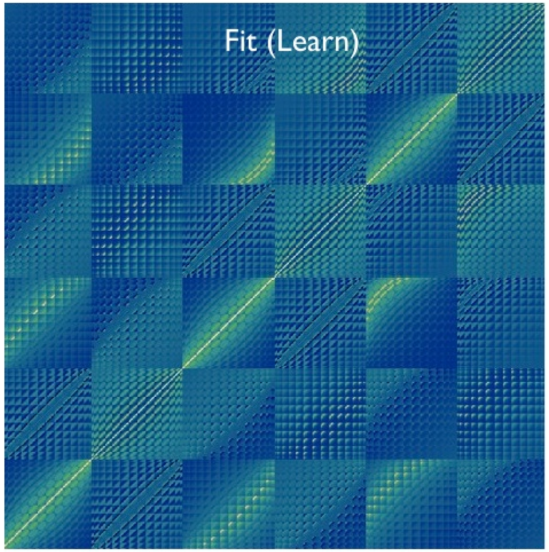
  - Measure and fit covariance matrices between WFS



What is MCAO ?

- Adaptive Optics:
  - Why MCAO ?
  - Tomography :
    How to reconstruct
    the atmosphere in 3D ?
  - Measure and fit covariance matrices between WFS
  - Learn&Apply
    (CANARY 2010)



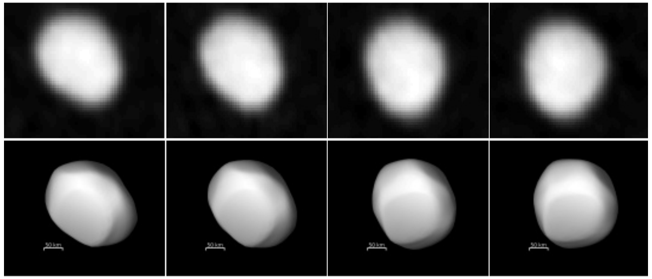


What is MCAO ?

- Adaptive Optics: MAORY configuration
  - 6 LGS (may-be 8)
    - Ø1.5arcmin (0.45'' radius)
  - 3×2 NGS WFS (LOR)
    - 3 modules on X-Y stages patrolling Ø3arcmin field
    - Low-Order fast IR WFS: 2×2 subaps @SAPHIRA ?
    - Reference WFS: 10×10 subaps @CCD220 camera
  - 2 DM:
    - Conjugated @6km & 15km
    - ~700 modes (actuators) ~30×30

MAORY — MICADO science cases

- Adaptive Optics: MAORY science case
  - Solar system

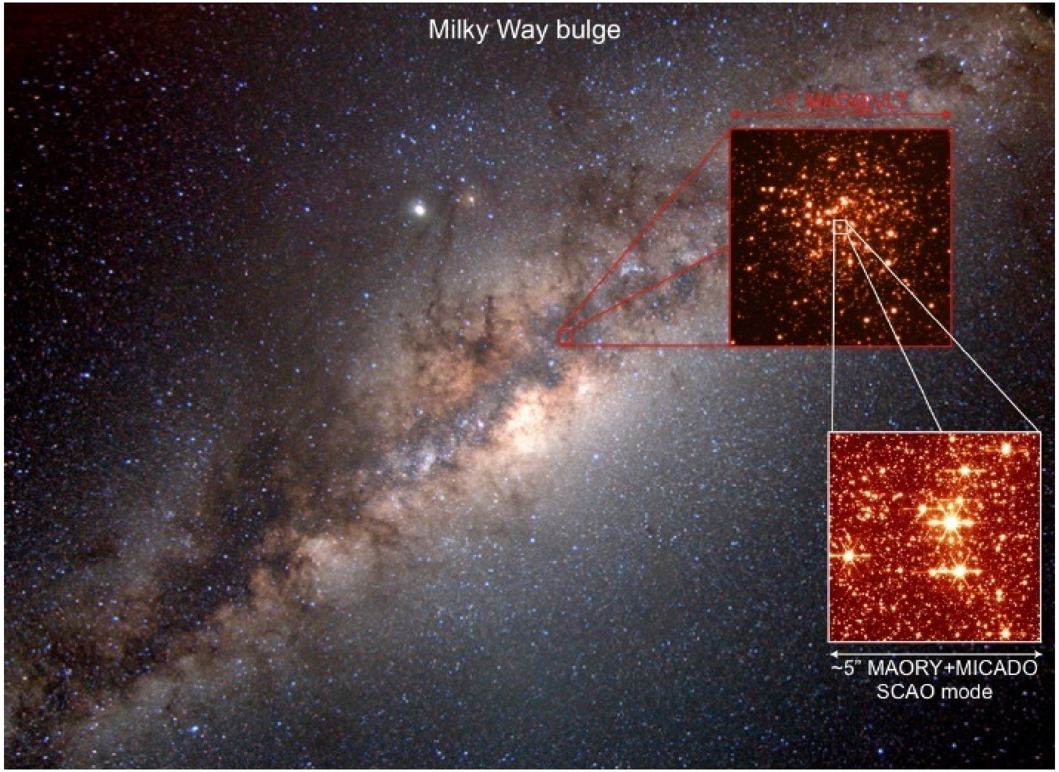


Juno by par SPHERE@VLT

Figure 8: J, H and K' color composite of Uranus (left), H and K' color composite of Neptune (middle) and K' image of Titan (right). The inset on the top left is an enlarged image of Miranda at K'.

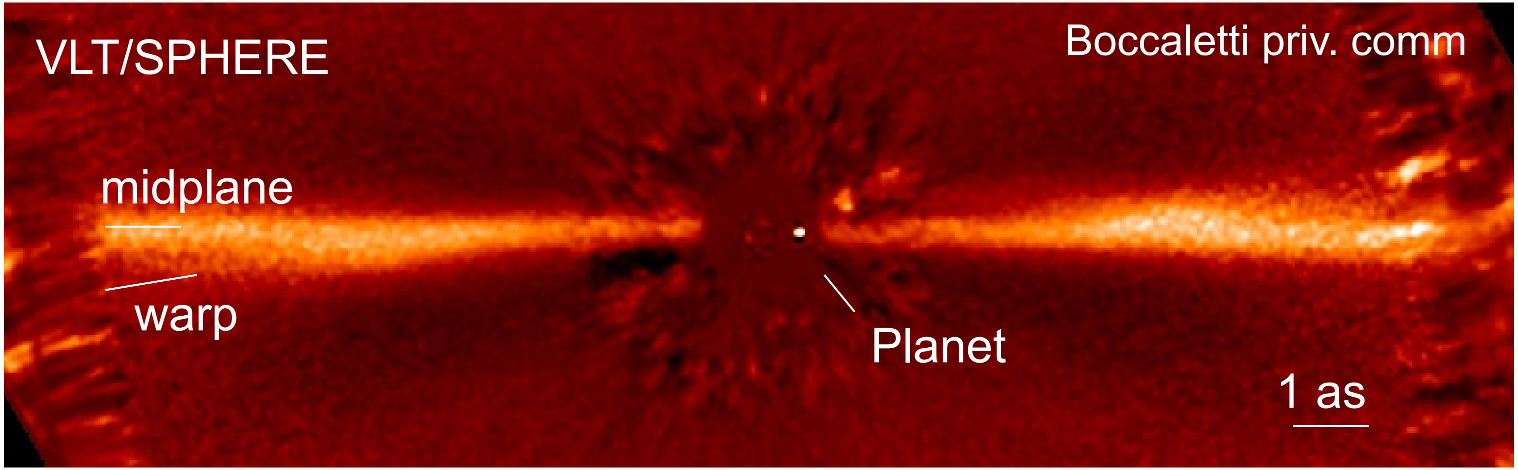
MAORY — MICADO science cases

- Adaptive Optics: MAORY science case
  - Star formation and evolution in nearby stellar systems
  - MCAO: justified by the PSF uniformity and the astrometric precision over a large FOV (50”) that will increases stellar statistics.



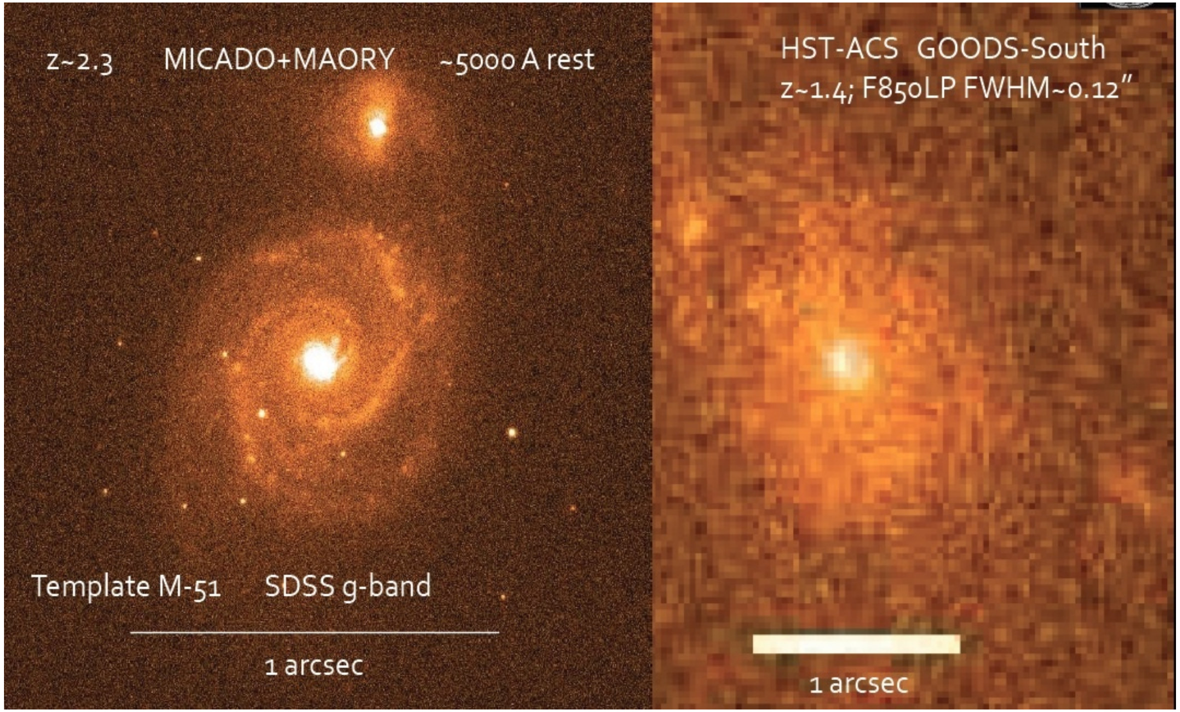
MAORY — MICADO science cases

- Adaptive Optics: MAORY science case
  - Disks and Exoplanets
  - Pure SCAO science case with angular differential imaging & coronography



MAORY — MICADO science cases

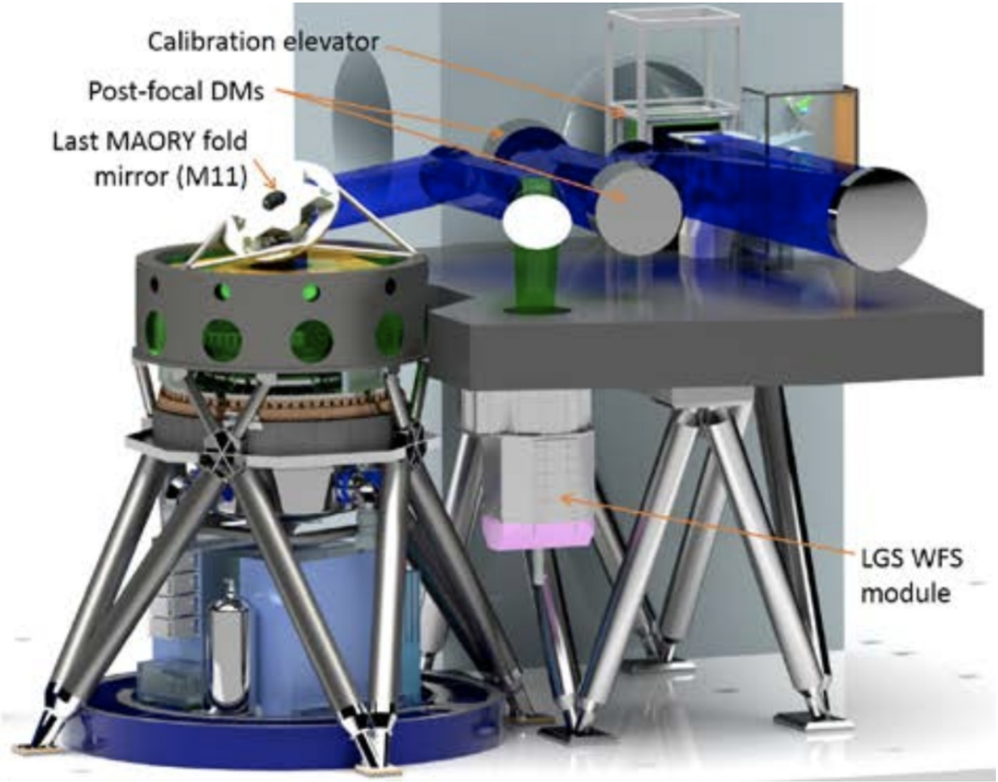
- Adaptive Optics: MAORY science case
  - High redshift universe
  - MCAO is preferred for AO sky coverage issue, PSF uniformity over large field, and target magnitude constraint.



MAORY Optical Design History

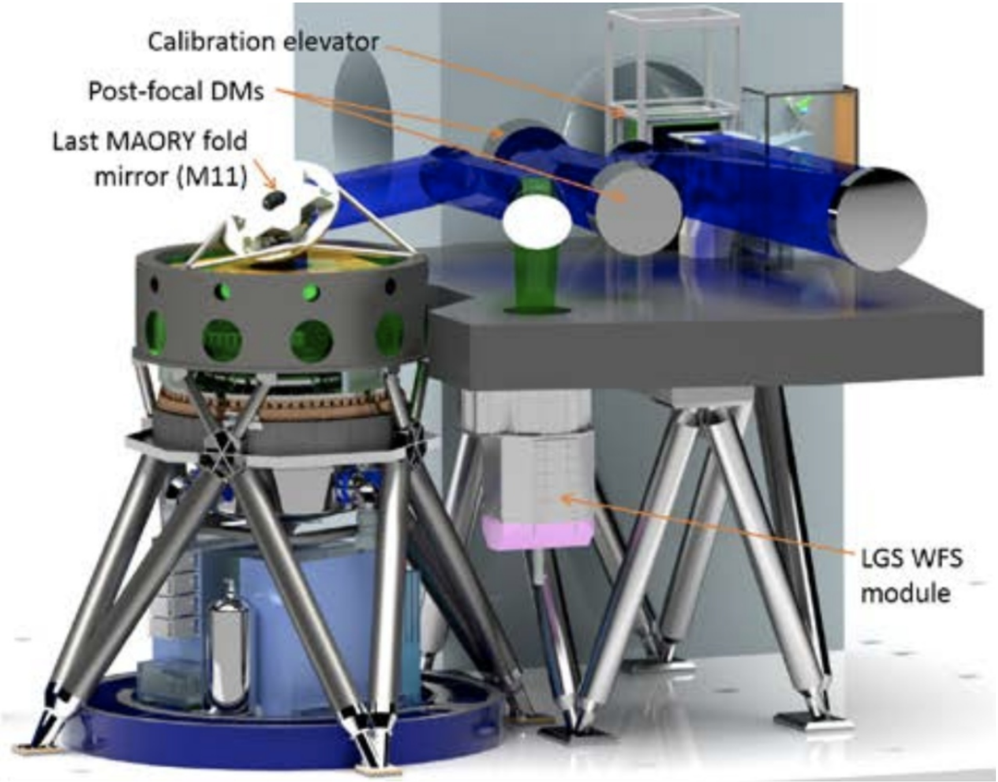
MAORY Optical Design History

- MICADO: what is it ?
  - General purpose imager for ELT (~CONICA was for VLT)
  - 1'×1' field of view, zoom mode 20''×20'', spectrographic and cornographic modes
  - 9 (3×3) Havaii4 RG (12000×12000 = 144 Mpixels !!!)
  - Cryostat Ø2.5m, on Nasmyth platform, rotation gravity invariant



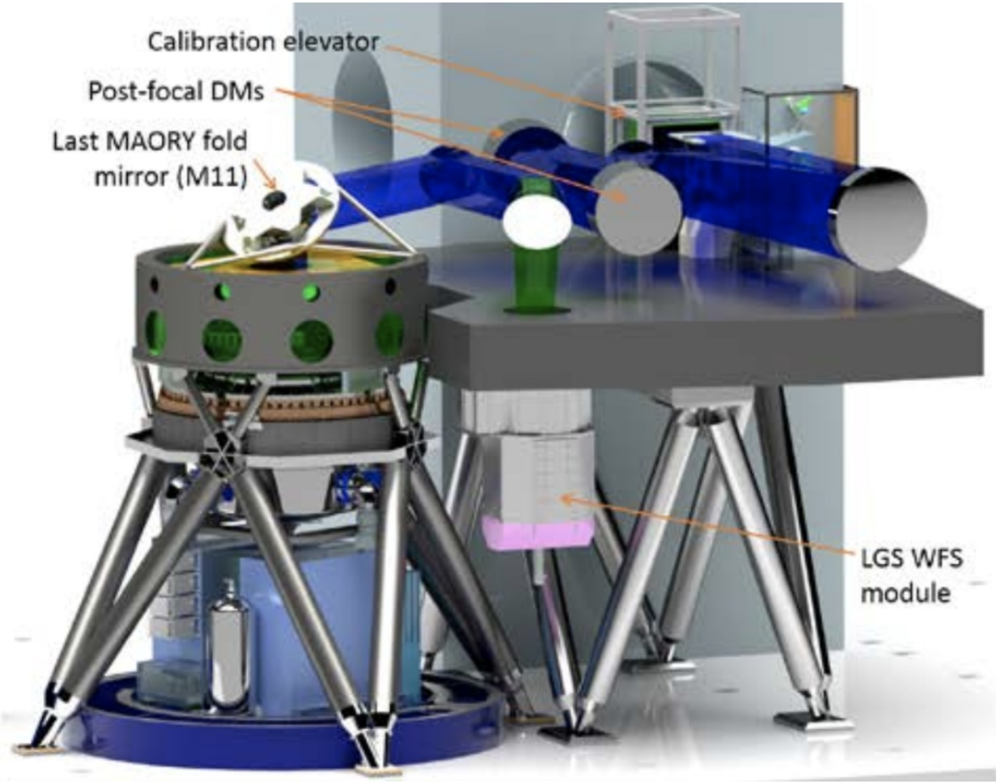
MAORY Optical Design History

- MICADO history:
  - Contract signed: 18 sept 2015
  - Instrument kick-off: 6 oct 2015
  - PDR: november 2018
  - FDR: end 2020 (TBC)
  - PAE: 2024
  - PAC SCAO: 2025
  - PAC MCAO: 2027



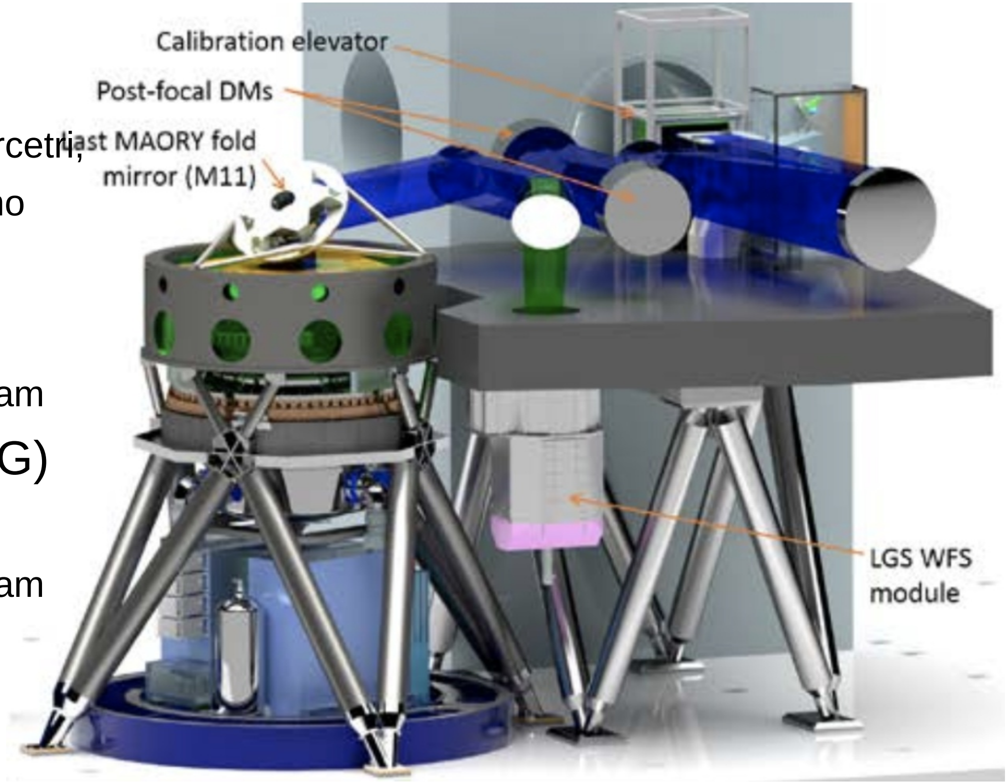
MAORY Optical Design History

- MICADO → MAORY specifications
  - defined in #ESO-254311
  - Field of View :
    - MICADO science : Ø70 arcsec
    - MAORY technical FoV: Ø3arcmin
    - 2nd port : >Ø2.5arcmin
  - Magnification : 1:1
  - Throughput : >65%
  - 2 DMs
  - AO: 50% Strehl λ=2.2µm @50% sky-coverage
  - Astrometry



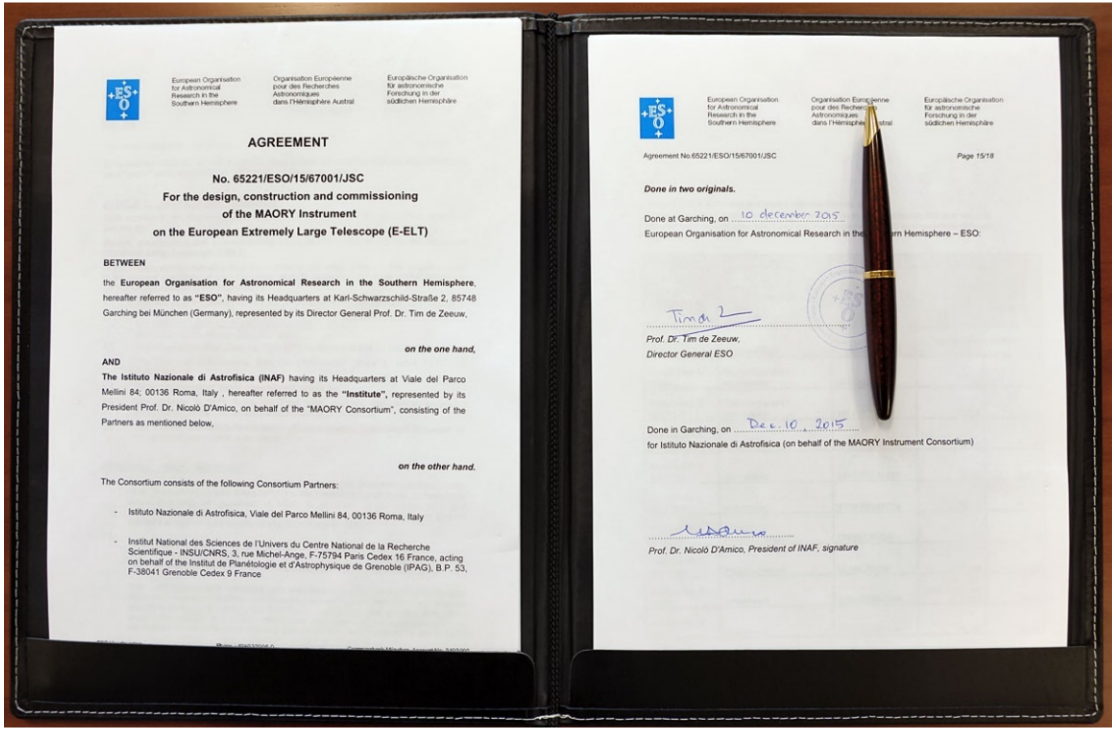
MAORY Consortium

- INAF (Italy)
  - Acting as Lead institute
  - System level of MAORY
  - 6 INAF Institutes are involved: OAS Bologna, OA Arcetri,
  - OA Brera, OA Capodimonte, OA Padova, OA Teramo
- INSU IPAG (France)
  - LGS wavefront sensor
  - Contribution to SAT, System Team and Science Team
- National University of Ireland Galway (NUIG)
  - Test and Wavefront Correction Verification
  - Contribution to SAT, System Team and Science Team
- ESO
  - Project customer
  - Supplier of components and services



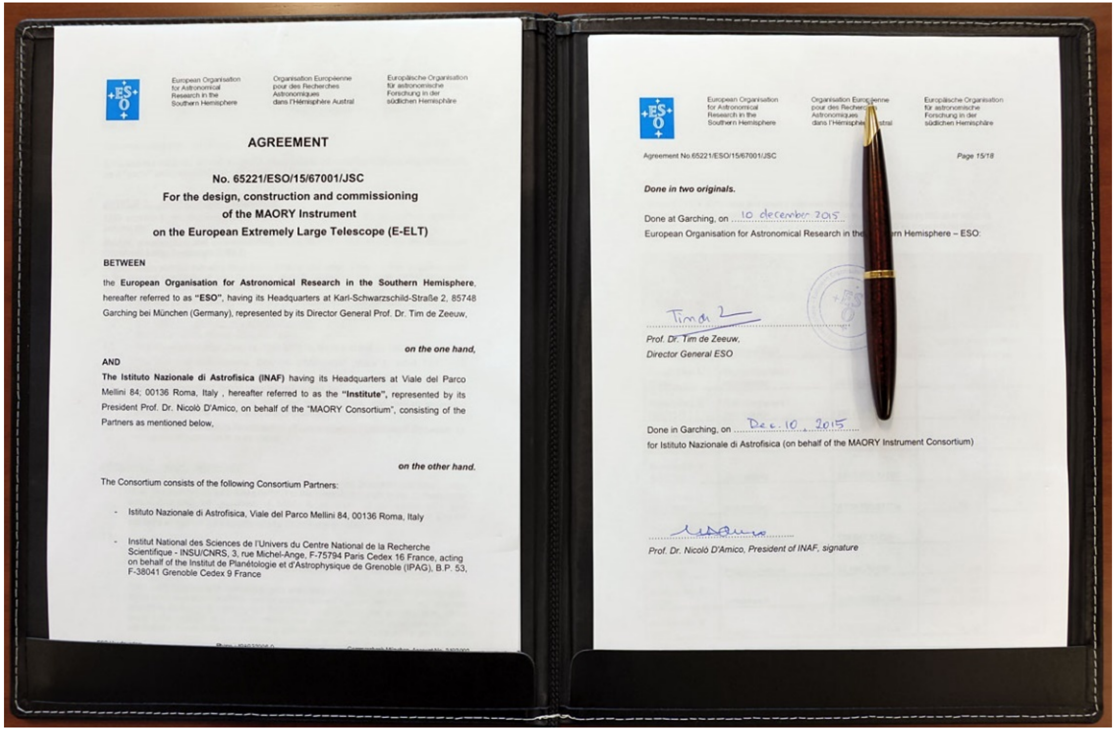
MAORY Instrument History

- Phase A
  - Nov 2007 - Dec 2009
  - Review held on December 10-11, 2009
- Phase B preparation
  - 2010 - 2015
  - Instrument re-baselining
  - Requirements definition
  - Contractual documents preparation
  - Consolidation of facilities at INAF
  - Consolidation of Consortium following ESO guidelines
- Agreement signature
  - 10 Dec 2015



MAORY Instrument History

- Conclusion of trade-off study
  - 14 Feb. 2020
- Phase B (PDR)
  - Feb. 2016 – Feb. 2021
- Phase C (FDR)
  - Feb. 2021 – Dec. 2022
- Phase D (MAIT)
  - Jul. 2021 – Mar. 2028
- PAE
  - Nov. 2027
- Phase E (Commissioning)
  - Mar. 2028 – Mar. 2029



MAORY Instrument History

Assessment - Summary

- Criterion 1: A feasible baseline instrument design compliant with the technical specifications and the interfaces to the ELT, MICADO and a 2nd port instrument partially compliant
  - good technical progress, AO design solid,
  - trade-off inconclusive and incomplete; maturity of MOC design insufficient
  - Non-compliances: mass, volume, 2nd port, only 6 LGS
- Criterion 2: A credible schedule for the design, development, construction, installation and commissioning of the MAORY instrument within the available budget partially compliant
  - PDR schedule (Apr 2020) not credible >> NET end 2020
  - Cost information limited >> but little difference between the options
  - Full cost estimate only at PDR

MAORY Optical Design History

- AMC : *Original design up to November 2018*
- MOC : *Design presented to ESO in July 2019*
- miniMOC : *Design evolution for weight-gain, october 2019, compatible with 2nd port if LGS-WFS duplicated*
- MMS : *Initial design proposed by ESO in september 2019, adapted and modified by MAORY team, proposed as base-line in january 2020, confirmation pending (february 2020 ?)*

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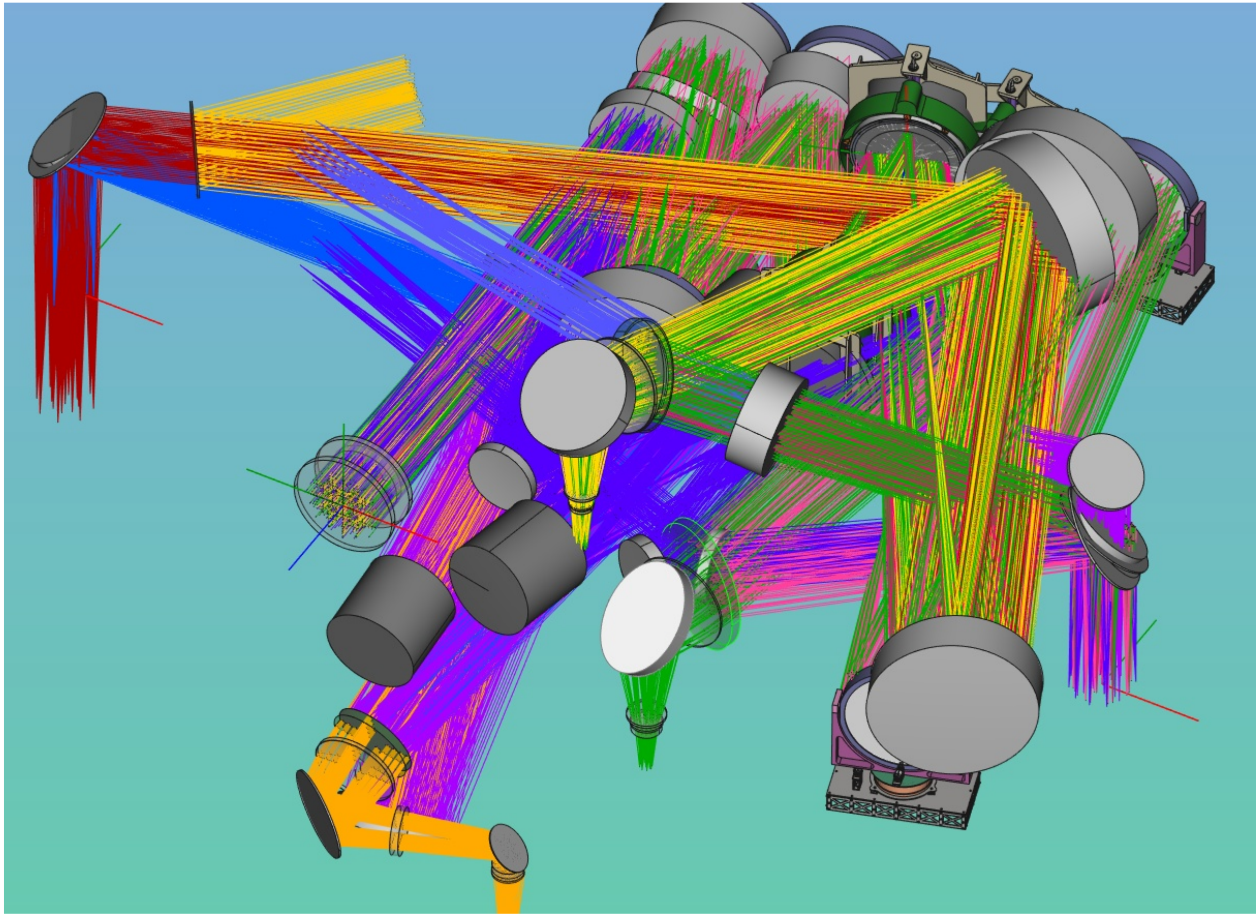
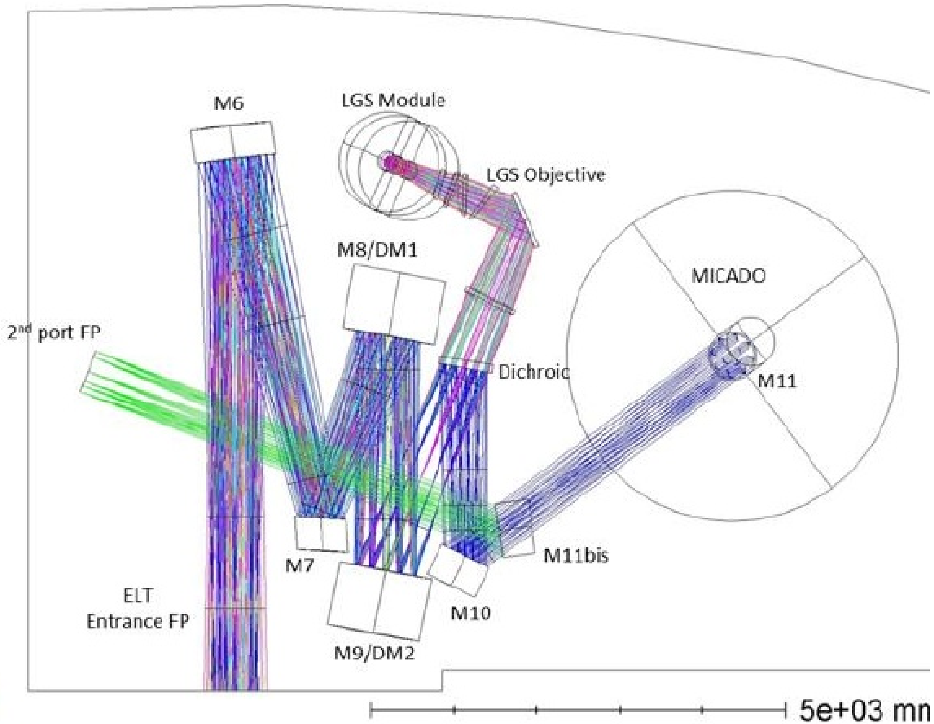


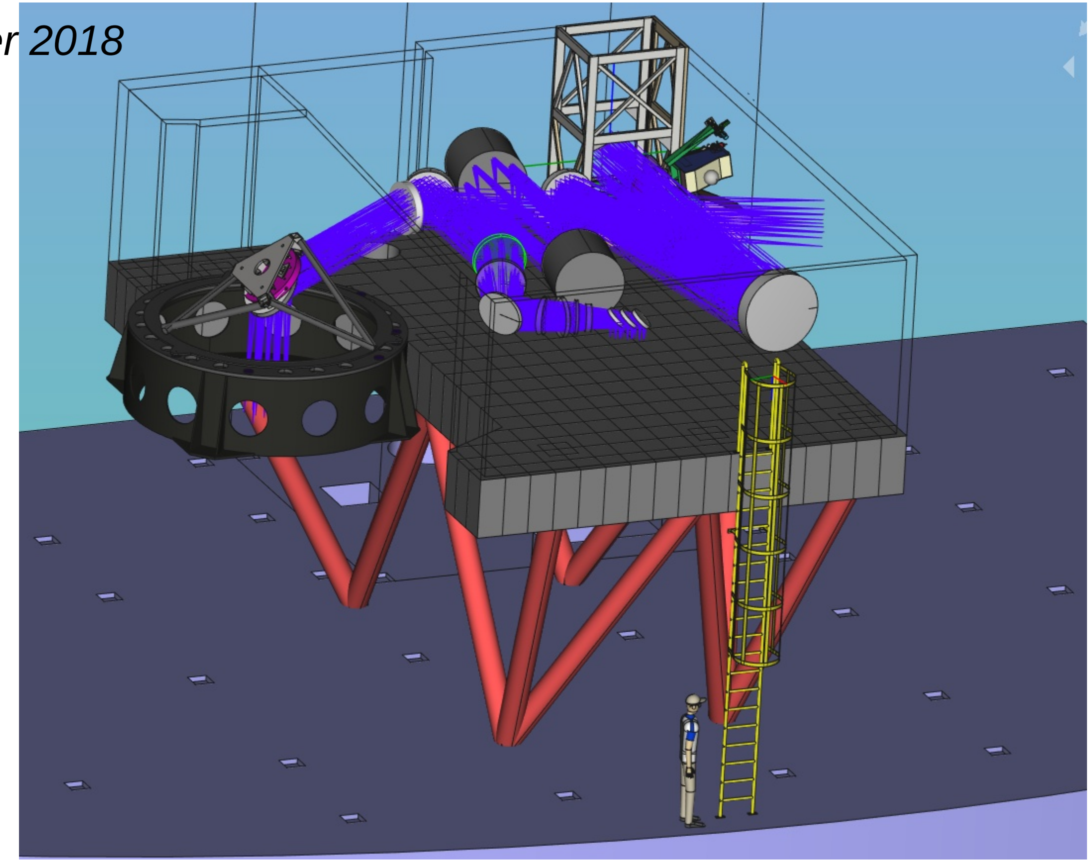
MAORY Optical Design History

- AMC : *Original design up to November 2018*
- Aspheric Mirror Concept
  - 5 aspheric surfaces
  - Difficult to manufacture
  - Difficult to align
  - Compact
  - Flat focal plane
  - Incompatible with latest 2nd port requirements



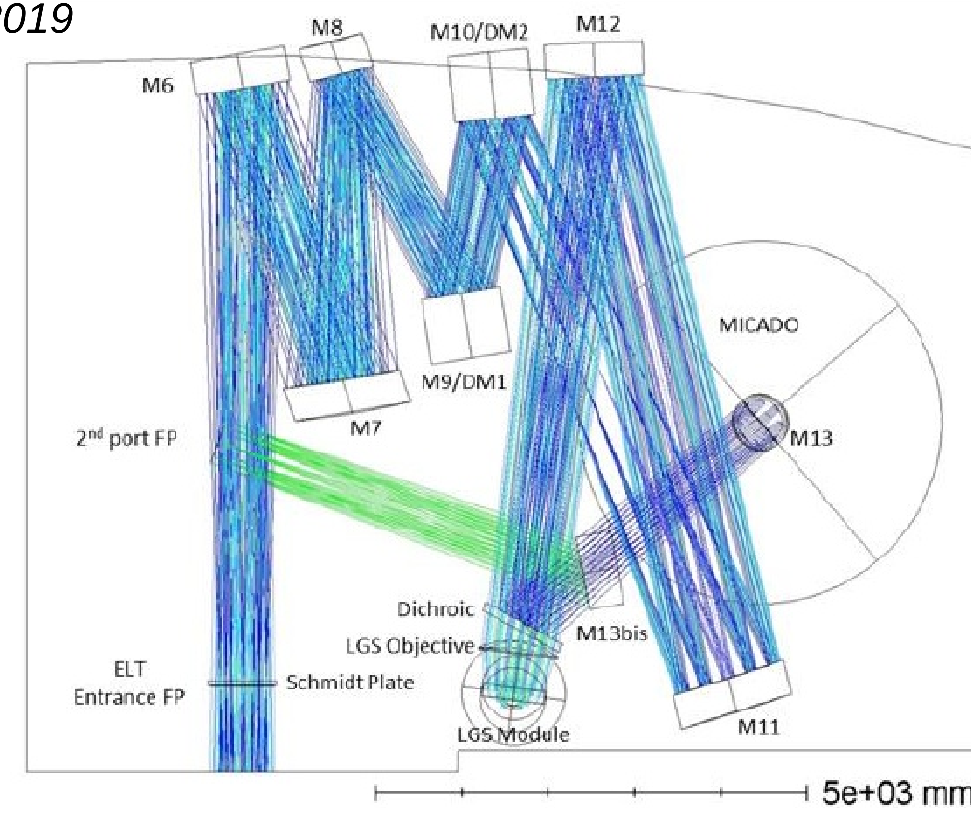
MAORY Optical Design History

- AMC : *Original design up to November 2018*
- Aspheric Mirror Concept
  - 5 aspheric surfaces
  - Difficult to manufacture
  - Difficult to align
  - Compact
  - Flat focal plane
  - Incompatible with latest 2nd port requirements



MAORY Optical Design History

- MOC : *Design presented to ESO in July 2019*
- Modified Offner Concept
  - Schmidt-plate
  - 2 flat Dms
  - Curved focal plane (R≃10m)
  - Big & Heavy
  - Easy manufacture & alignment



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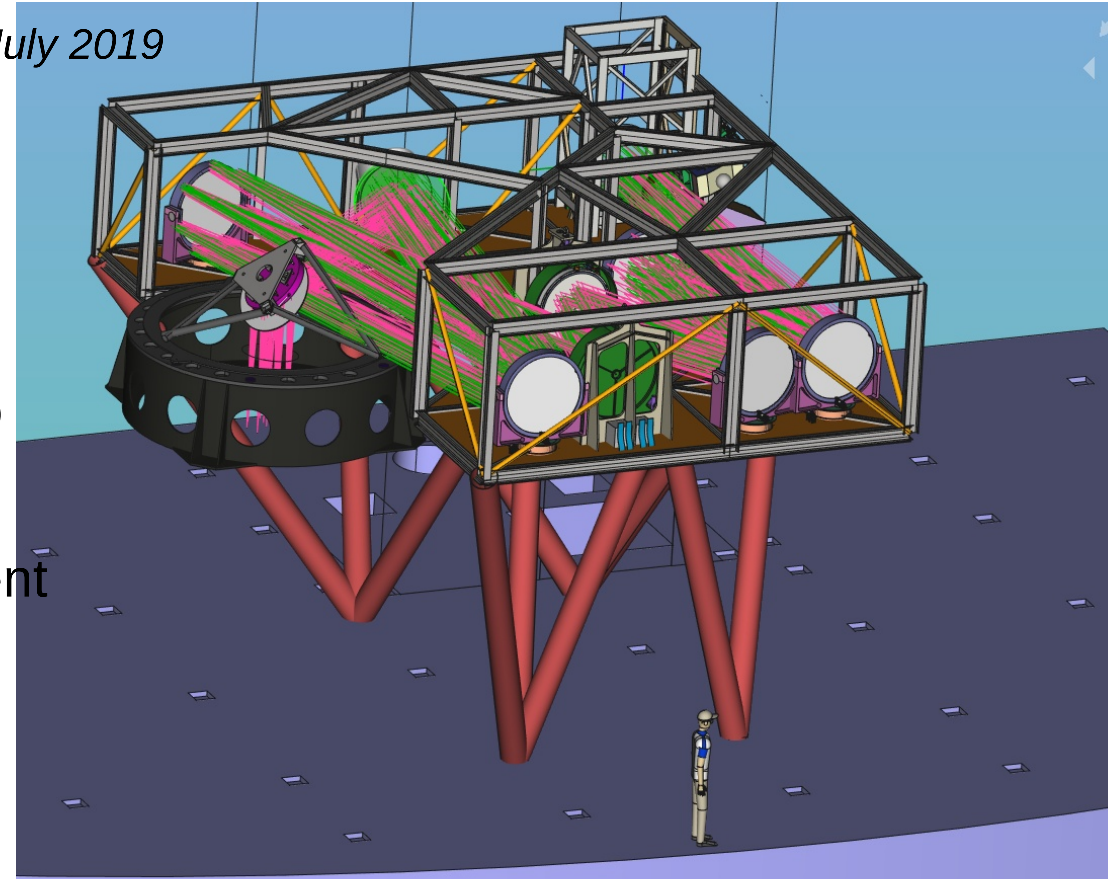
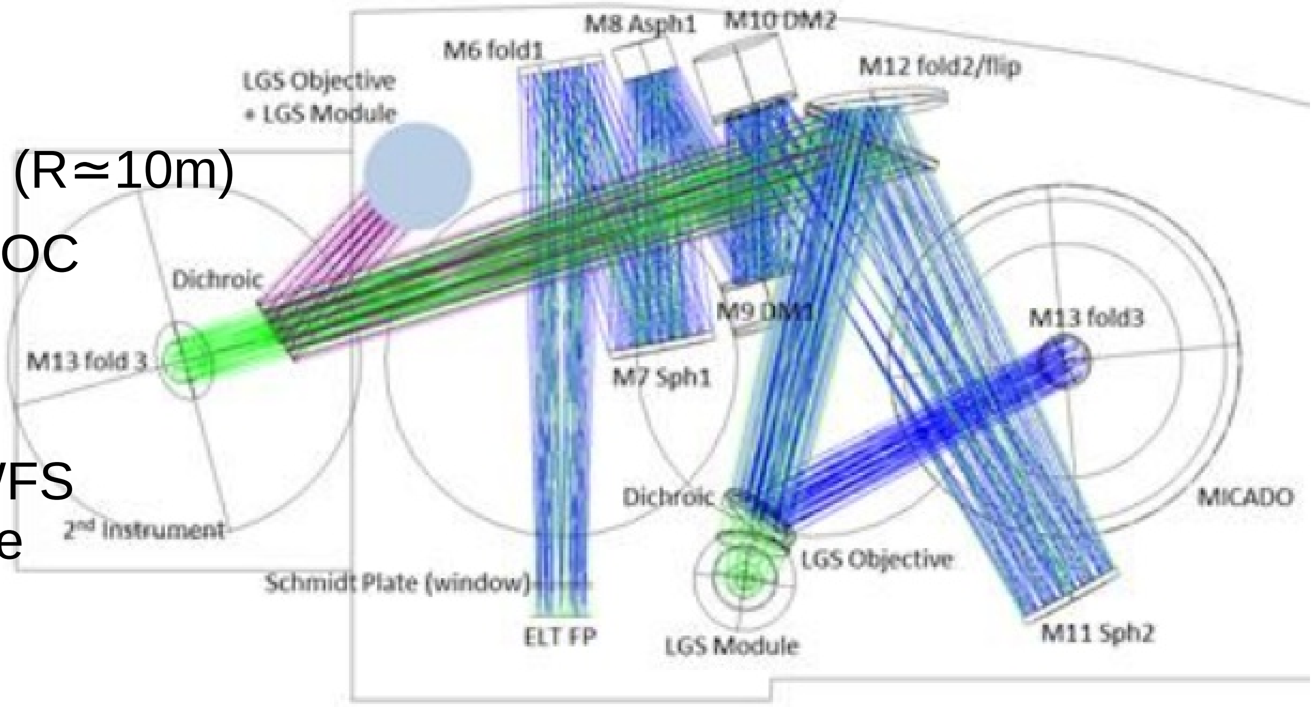


MAORY Optical Design History

- miniMOC : *Design evolution for weight-gain, september 2019*
  - Schmidt-plate
  - 2 flat Dms
  - Curved focal plane (R≃10m)
  - Smaller than the MOC
  - Easy manufacture & alignment
  - Duplicating LGS-WFS makes it compatible with latest 2nd port requirements



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  - 2 flat Dms
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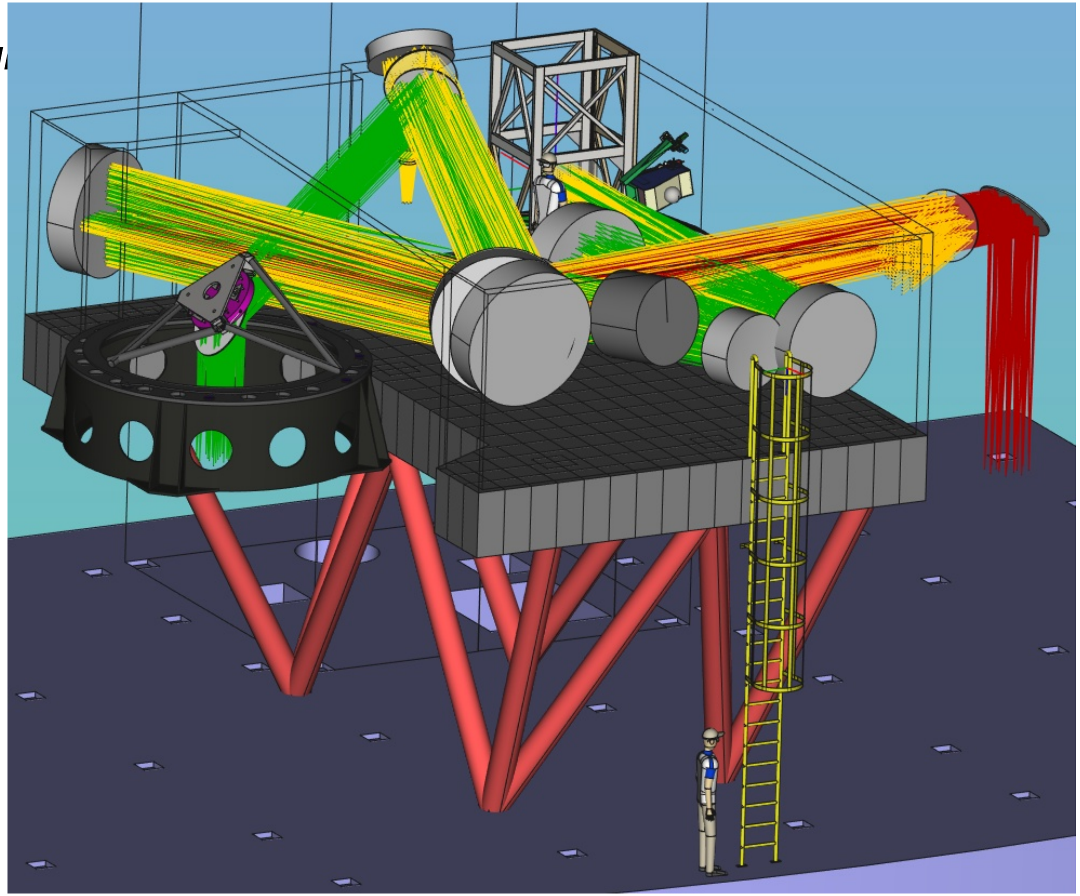
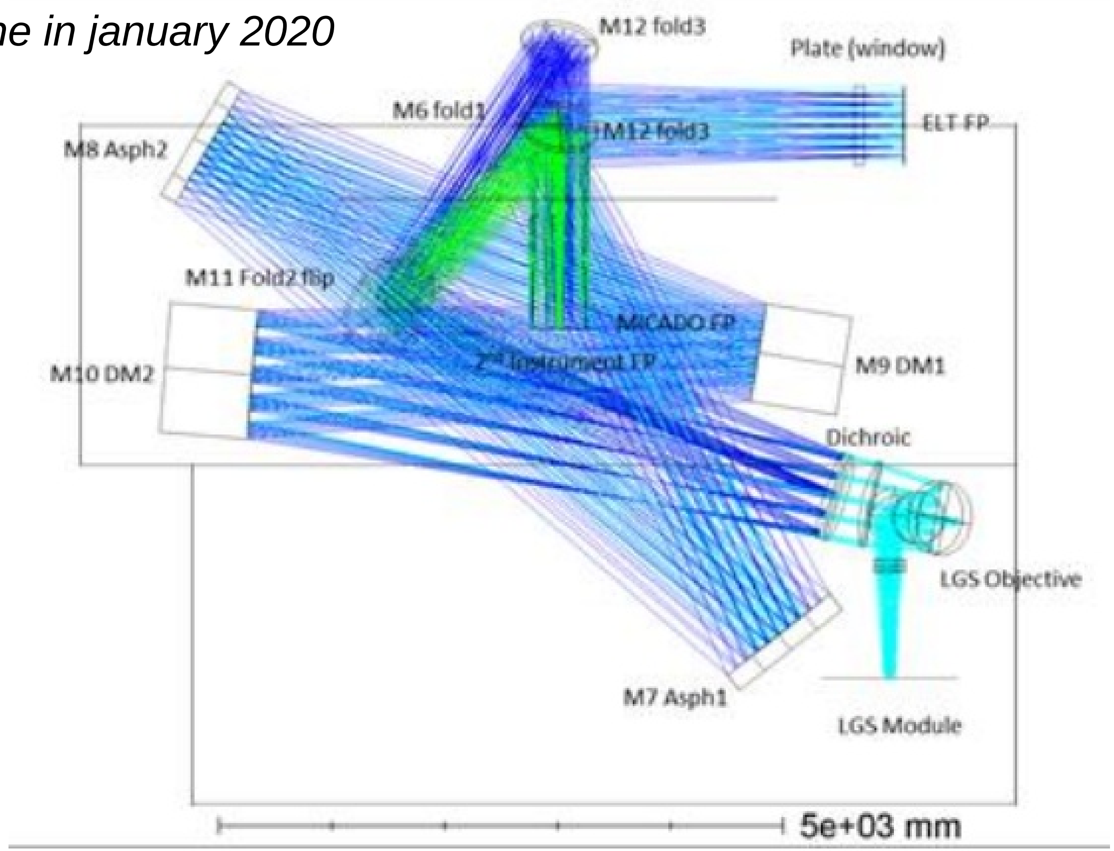


MAORY Optical Design History

- MMS : *Design proposed as base-line in january 2020*
  - Schmidt plate
  - Vertical plane
  - Curved Dms
  - Flat output focal plane
  - 3D laser tracker alignment



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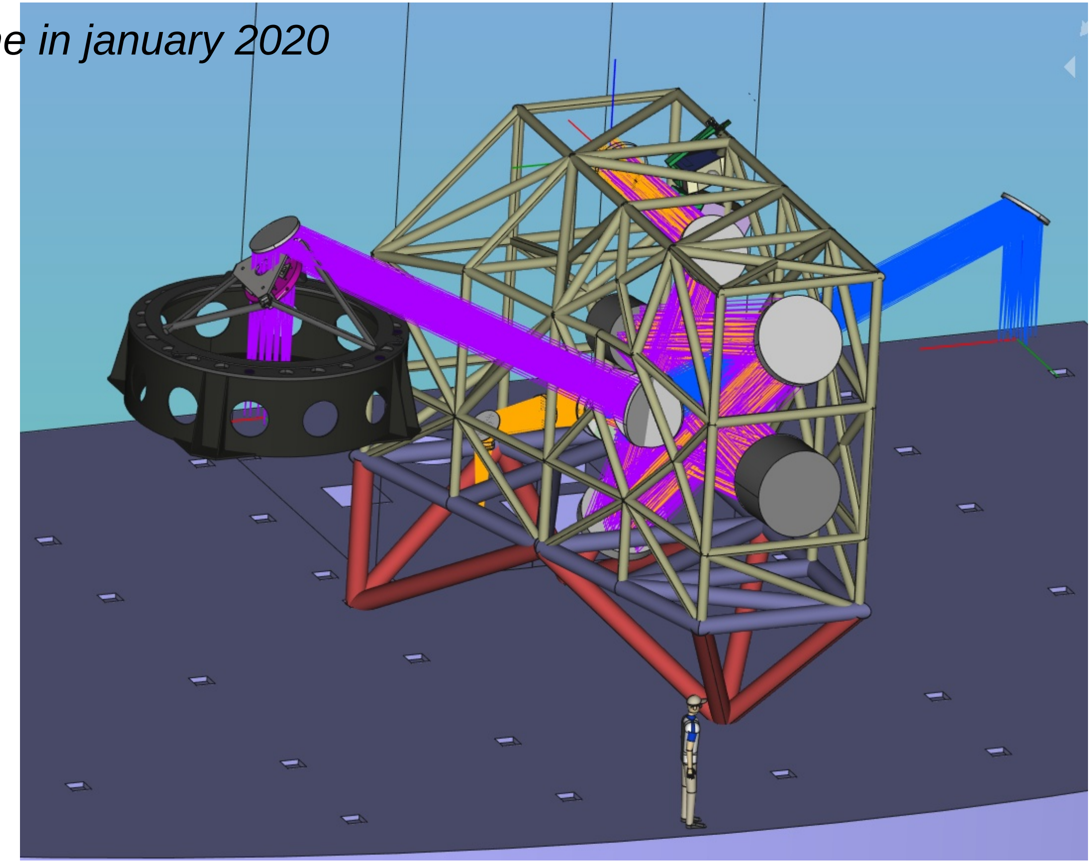
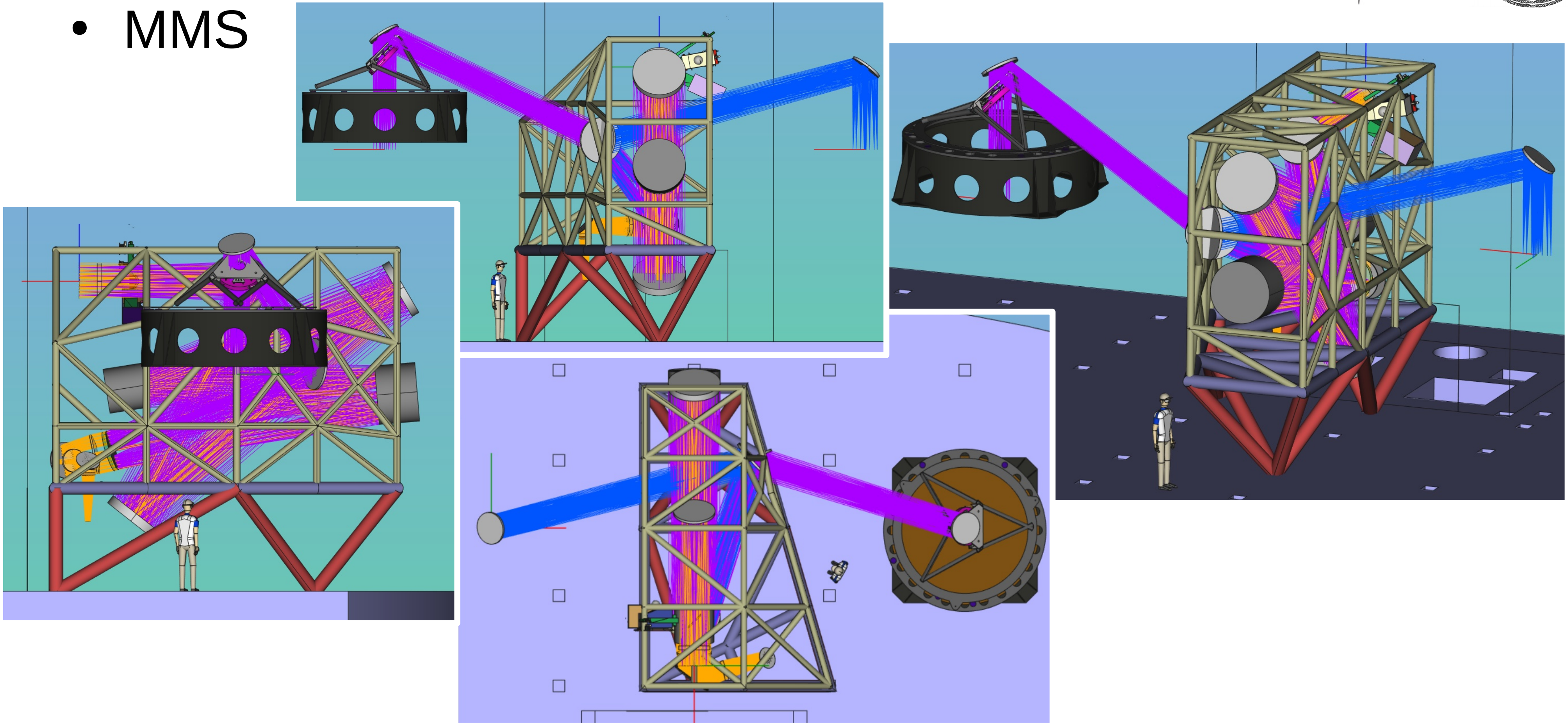


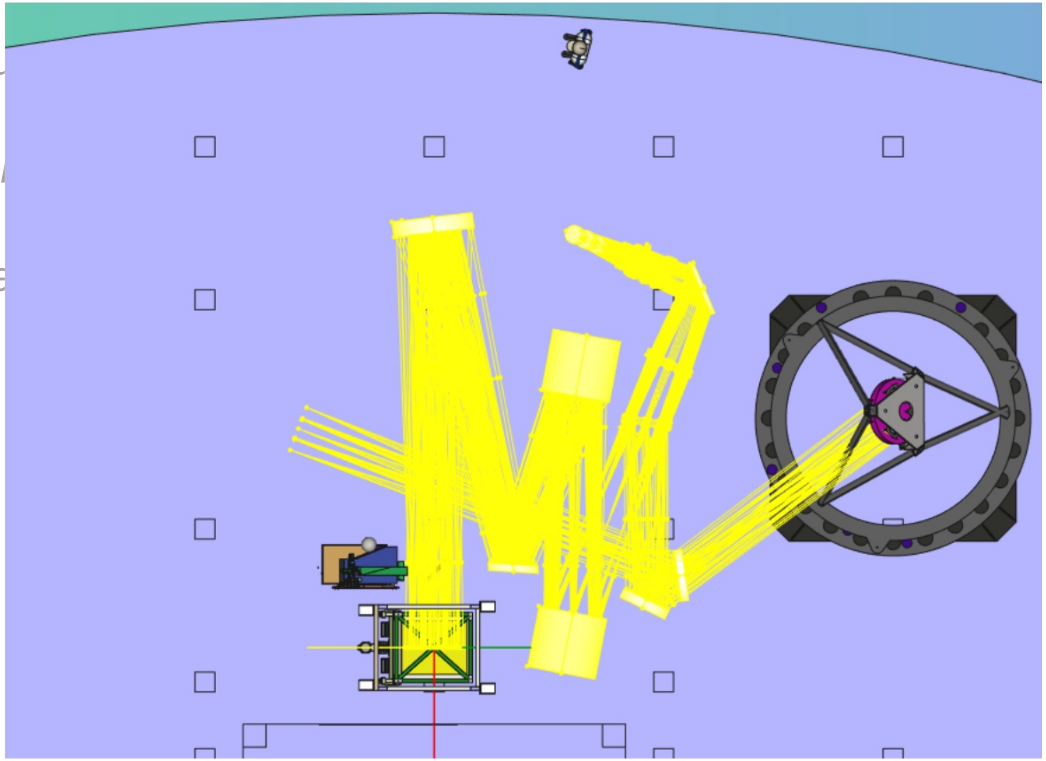
MAORY Optical Design History

- MMS



MAORY Optical Design Comparison

- AMC : *Original design up to November 2018*
- MOC : *Design presented to ESO in Ju*
- miniMOC : *Design evolution for wei*
- MMS : *Design proposed by ESO in se* *february 2020*



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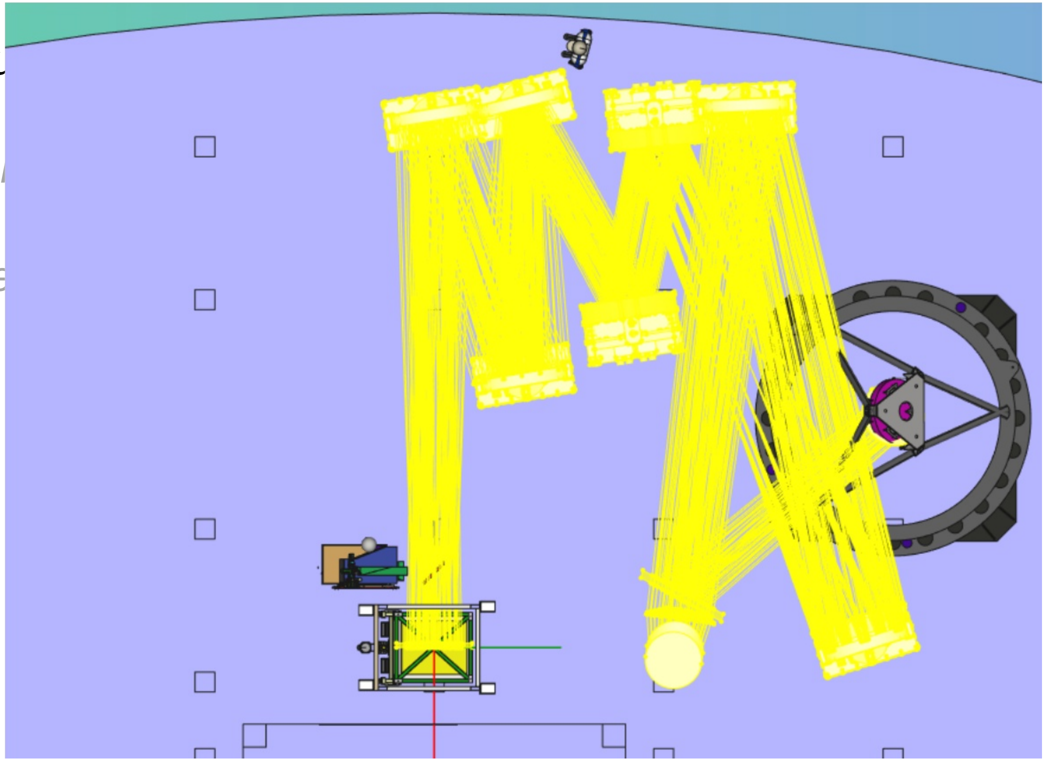

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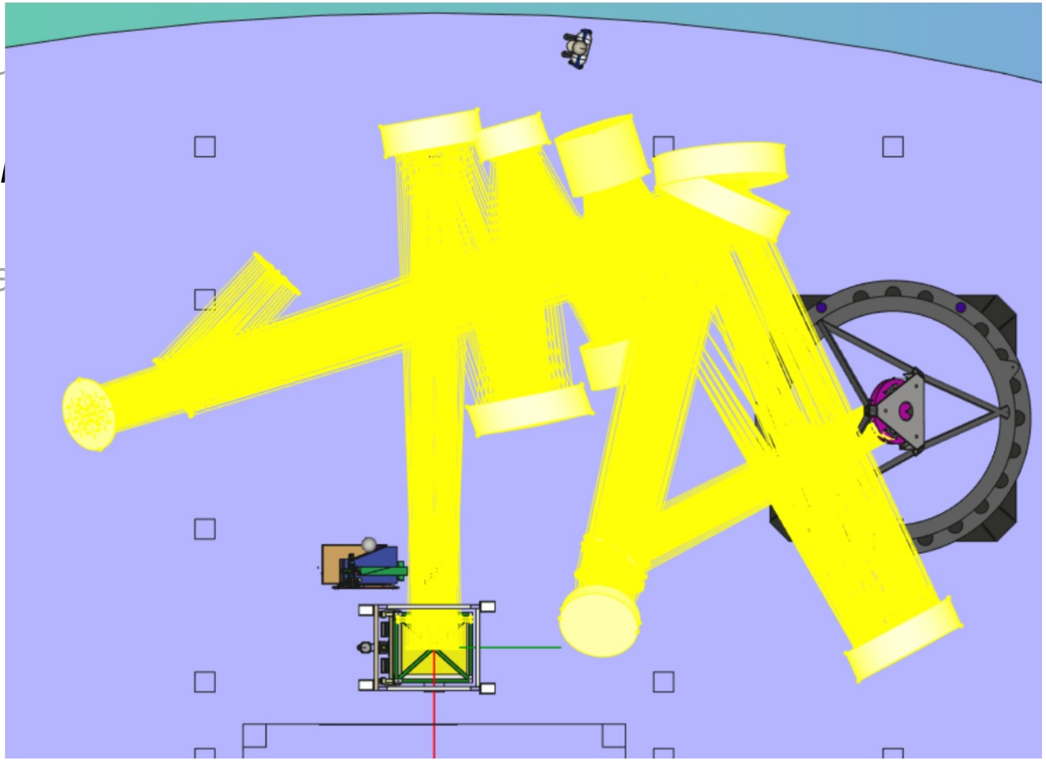

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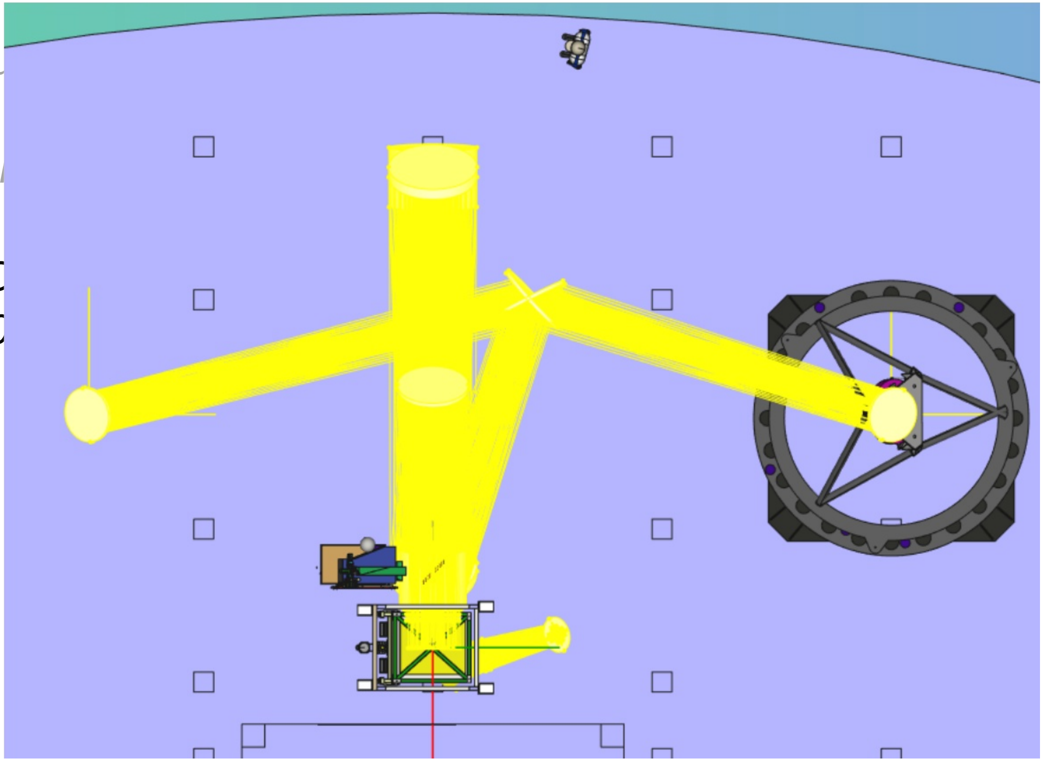


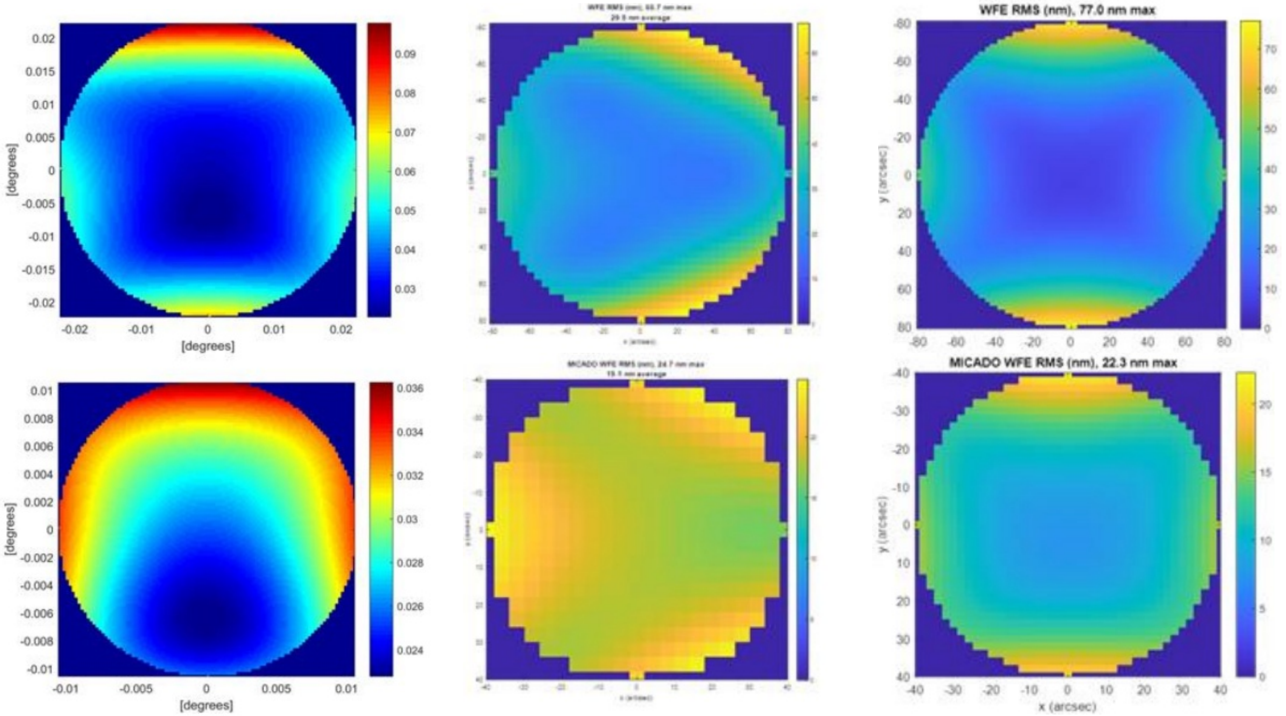
MAORY Optical Design Comparison

- Wave-front error maps:

AMC | MOC | MMS

Technical field (Ø3')

Science field (Ø1')



MAORY Optical Design Summary

SUMMARY:	ELT Nasmyth	AMC	miniMOC (MOC)	MMS
Plate-scale	3.316	1:1	1:1	1:1
Distortion (mas)		23.2	10.2	43
Distrosion variation (mas) req. <3		1.0	0.19	0.26
WFE science field (nm rms) req. <40		35	32	25
WFE technical field (nm rms) req. <120		90	75	75
Field curvature (m)	9.884	∞	9.283 (9.496)	∞
Numerical aperture	f/17.75	f/17.75	f/17.46	f/17.76
Pupil distance (m)	37.868	9.128	27.1 (25.513)	14.0
Pupil size (mm)	2134	514	1566 (1461)	788
Number of optics		7 reflections	9 reflections + plate	8 reflections + plate
Aspheric surfaces		5	1 mirror + plate	2 mirrors + plate
Max size of optics (m)		≃1.00	≃1.25 (1.40)	≃1.15
DM shape		conic	flat	spherical
Conjugate altitude (km)		4.3 & 15.0	6.9 & 16.0	6.9 & 17.5
Size of LGS dichroic		≃700mm	≃1000mm	≃800mm
Number of LGS optics		5 lenses + 2 mirrors	4 lenses + 1 mirror	4 lenses + 2 mirrors

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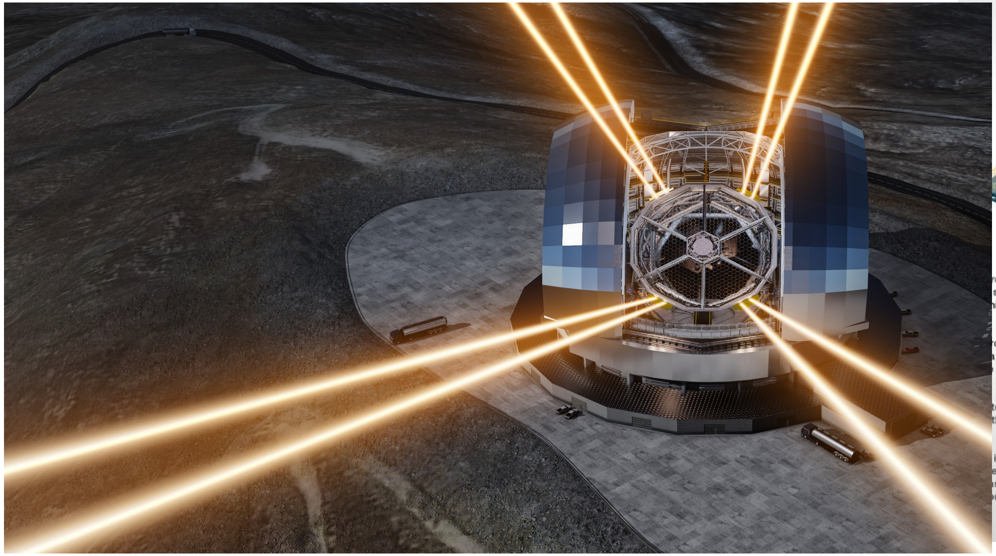
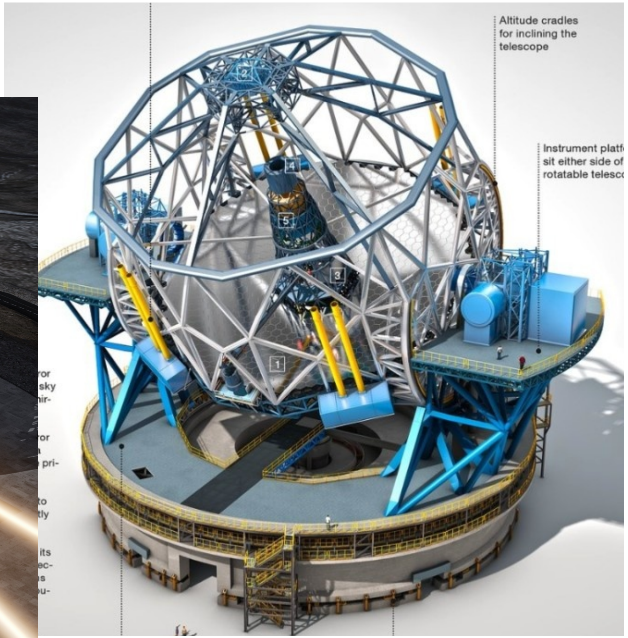
LGS-WFS subsystem

LGS-WFS subsystem

- Requirements:
  - 6 or 8 LGS-WFS
  - ELT elevation from 1.5° to 60°
  - Side launch





LGS-WFS subsystem

- Requirements:
  - 6 or 8 LGS-WFS
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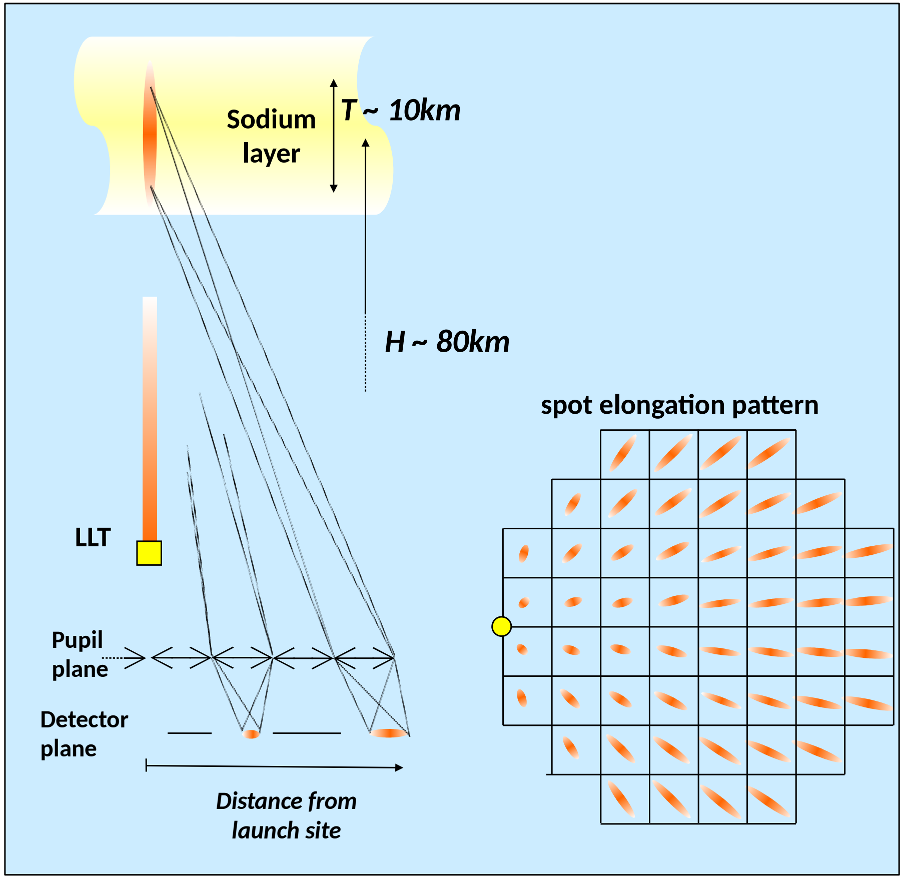
  - Spot elongation:
    - Sodium layer at finite distance



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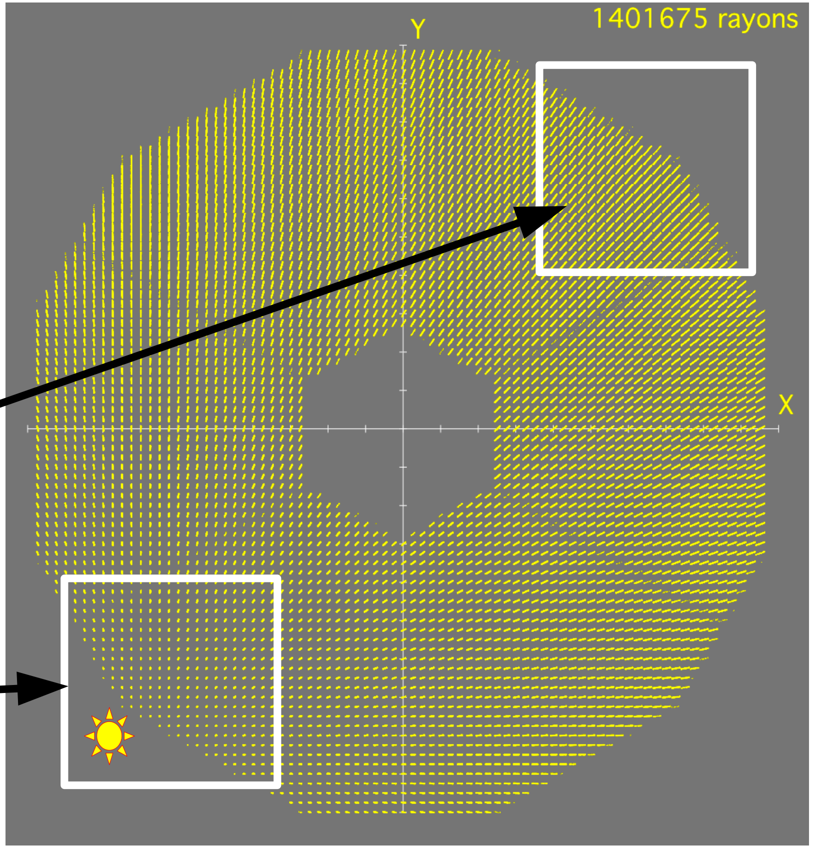
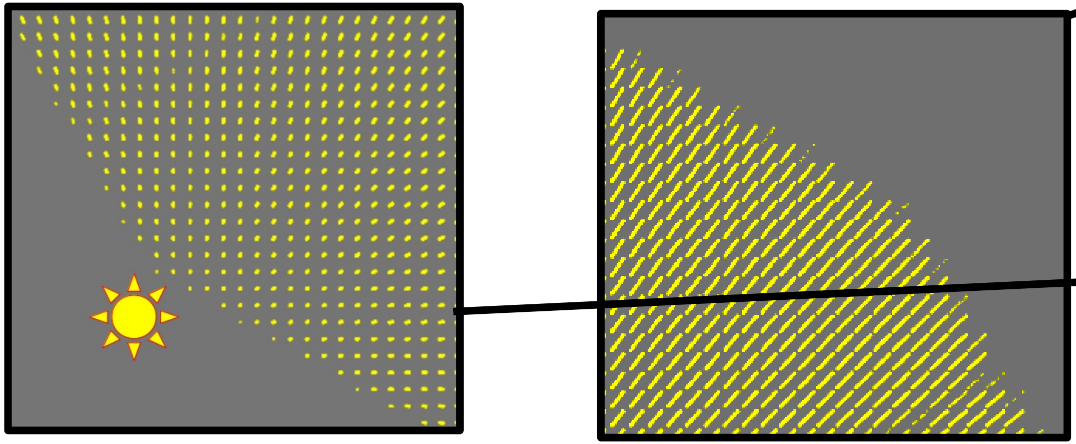


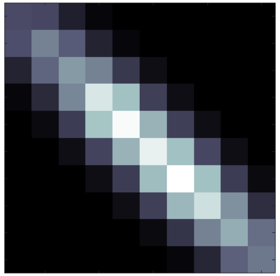


LGS-WFS subsystem

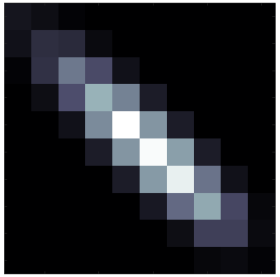
- Requirements:
  - 6 or 8 LGS-WFS
  - ELT elevation from 1.5° to 60°
  - Spot elongation:
    - Sodium layer at finite distance
    - Side-launch
    - Spot size ≃1arcsec
  - To avoid truncature: field stop ≃15arcsec (simulated: 10, 15, 20)
  - Configurations:

LISA LVSM detector 800×800, 24µm px	**Sony IMX425 detector 1100×1604, 9µm**
80sp × 10px = 800px	84sp × 13px = 1092px
66sp × 12px = 792px	78sp × 14px = 1092px
57sp × 14px = 798px	68sp × 16px = 1088px

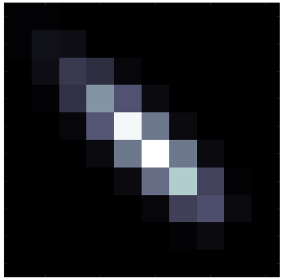
Field-stop 10''



Field-stop 15''

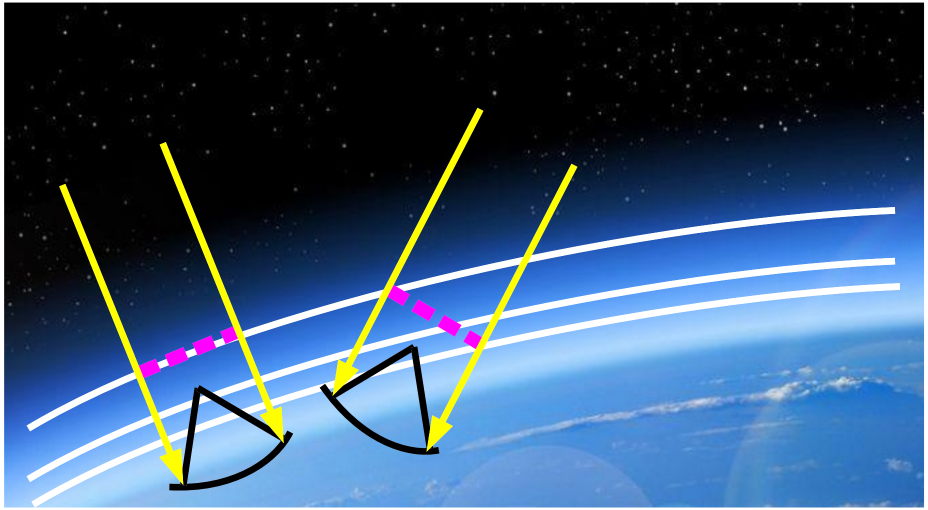


Field-stop 20''



LGS-WFS subsystem

- Requirements:
  - 6 or 8 LGS-WFS
  - ELT elevation from 1.5° to 60°
    - Focus follows ELT elevation: with sodium layer at 85km, distance to sodium layer from 85km to 160km



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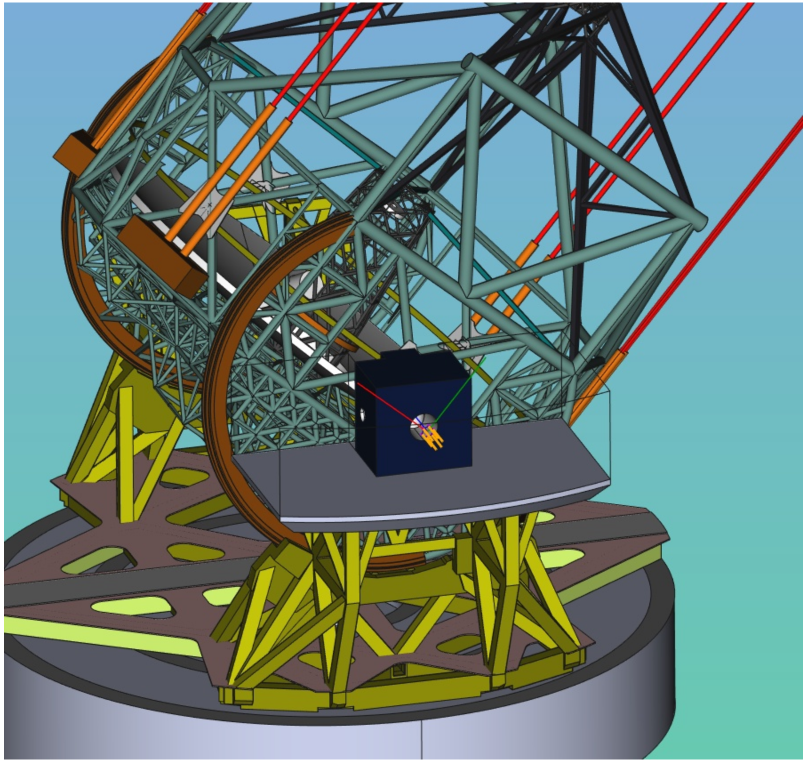
  - 6 or 8 LGS-WFS
  - ELT elevation from 1.5° to 60°
    - Focus follows ELT elevation: with sodium layer at 85km, distance to sodium layer from 85km to 160km
    - $\Delta focus_{LGS/\infty}$ = 2.493m - 6.914m = 4.421m
      - Nasmyth f/17.75
      - LGS objective : f/5
    - $\Delta focus_{LGS}$ = $4.521\,m \times \left(\frac{5}{17.75}\right)^2 = 350\,mm$

Straight Through Focus (A1)	
Object at Infinity	-27200
Laser Beacon at 200km	-29693
Laser Beacon at 80km	-34114

LGS-WFS subsystem

- Nasmyth LGS focus (LGS asterism constellation) rotates with ELT pupil (M1 & M4)
- Follows elevation
- For the LGS-WFS, a unique rotator follows focus **AND** pupil
- For NGS-WFS (like SCAO) MICADO derotates field + K-mirror derotates pupil



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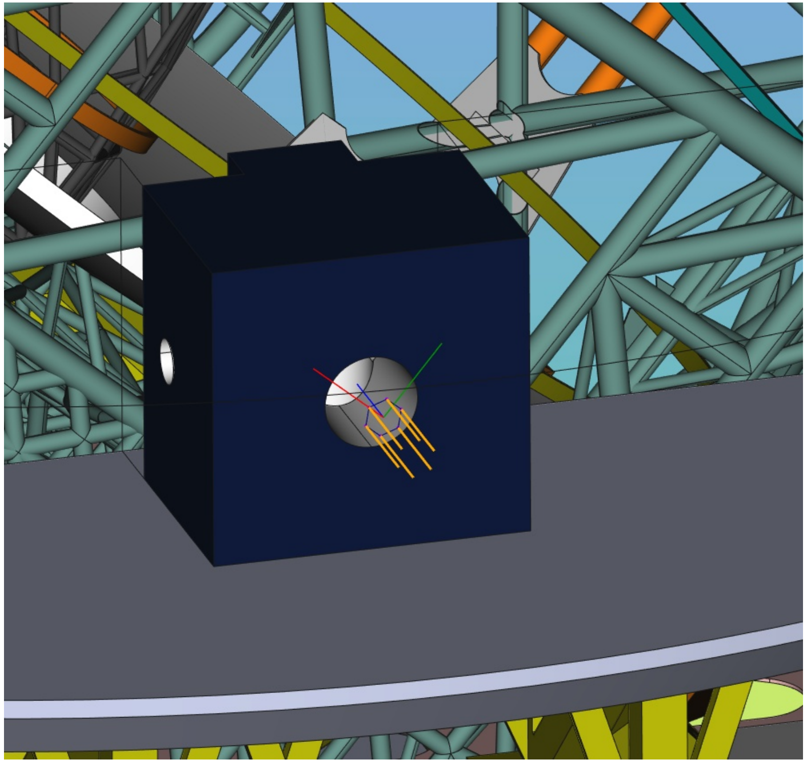

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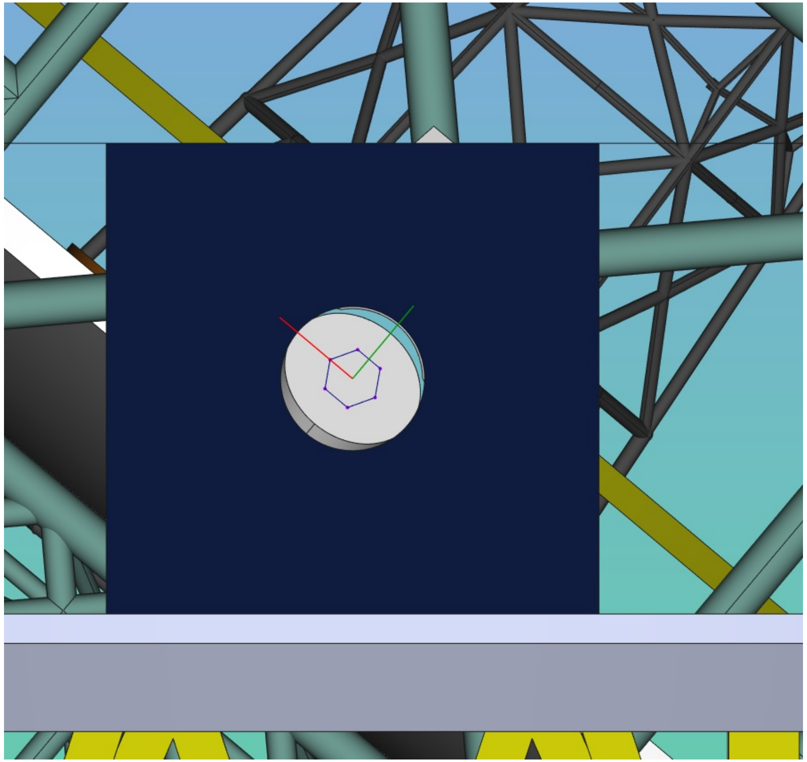


LGS-WFS Requirements

- Requirements:
  - 6 or 8 LGS-WFS
  - ELT elevation from 1.5° to 60°
    - Focus follows ELT elevation: with sodium layer at 85km, distance to sodium layer from 85km to 160km
      - $\Delta focus_{LGS}$ = 350mm
      - Max speed: 5mm/s (max 60s between target pointings)
    - LLT attached to ELT M1, M4 and M1 rotate together: LGS constellation follows M1 rotation:
      - Δrotation = 60°
      - For maintenance we plan 360°, cables detached
      - Max speed: 1°/s (max 60s between target pointings)

LGS-WFS Requirements

- Tech Spec rotation:
  - Max speed: 1°/s = 1 min for full 60° change → 1 min for presets
  - Acceleration 0.1°/s^2
  - Max range in operation 70°
    - Free rotation for AIT and maintenance (without cables): 360°
  - Wobble: *The wobble over any 90° rotation shall be less than 0.02° or 1 arcmin*
  - Run-out: *The runout over any 90° rotation shall be less than +/- 50µm*
  - Performance:

	Observation	Between 2 observations	Maintenance
Max angle	70° (TBC)	70°	360°
Speed	Max 1°/s – Min ≈	1°/s	Req: 1°/s Goal: 10°/s
Resolution	Req: 10'' Goal: 2''	NA	NA
Precision	Req: 40'' Goal: 20''	Req: 40'' Goal: 20''	

LGS-WFS Requirements

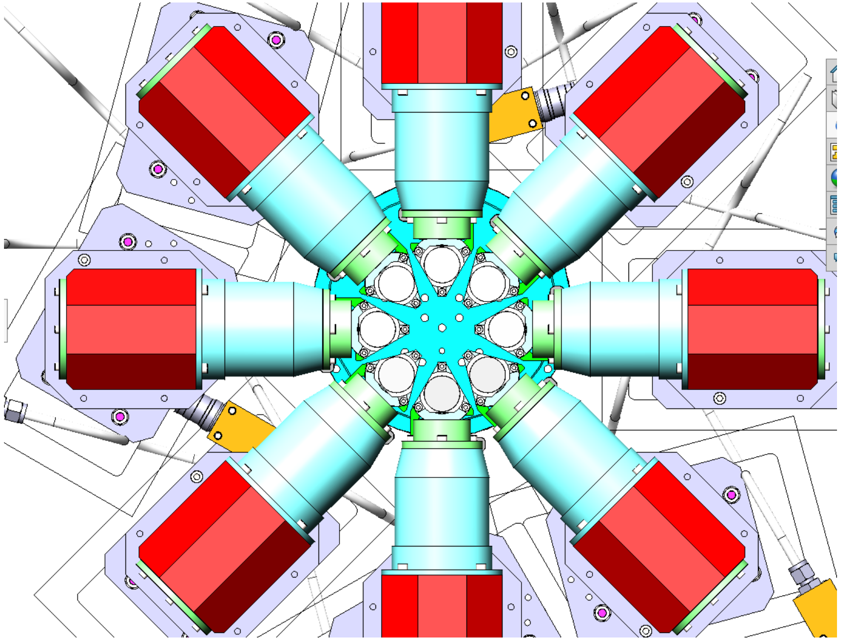
- Tech Spec alignment:
  - Θ-φ of derotator :
    - Δpupil < 0.5%
  - Θ-φ of translation :
    - ΔX_{focus} < 0.1 ” (~1/10th pixel)

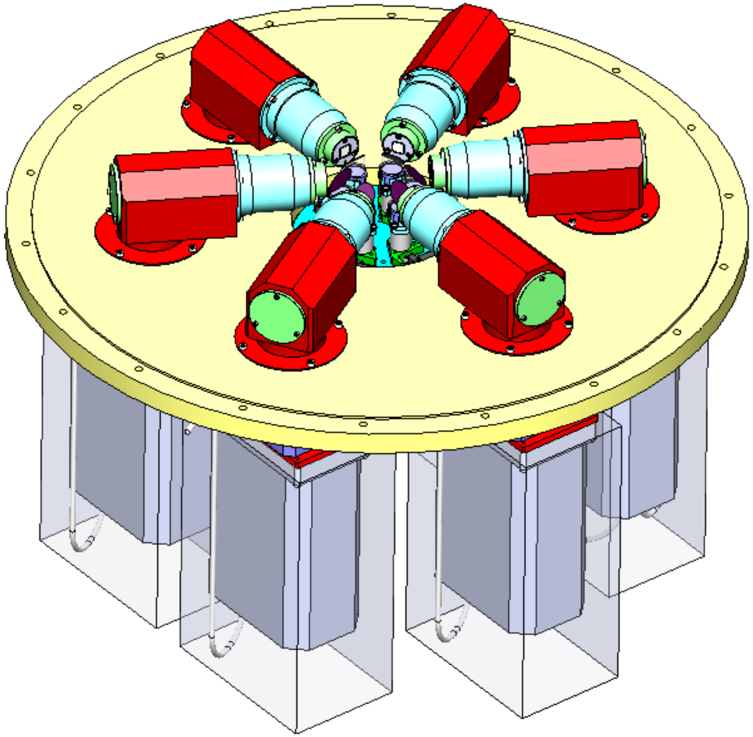
      → With platescale 1” = 1mm → 0.1mm (100µm)
  - X-Y of entire module :
    - ΔX_{focus} < 0.1 ” (~1/10th pixel)

      → With platescale 1” = 1mm → 0.1mm (100µm)

LGS-WFS Design

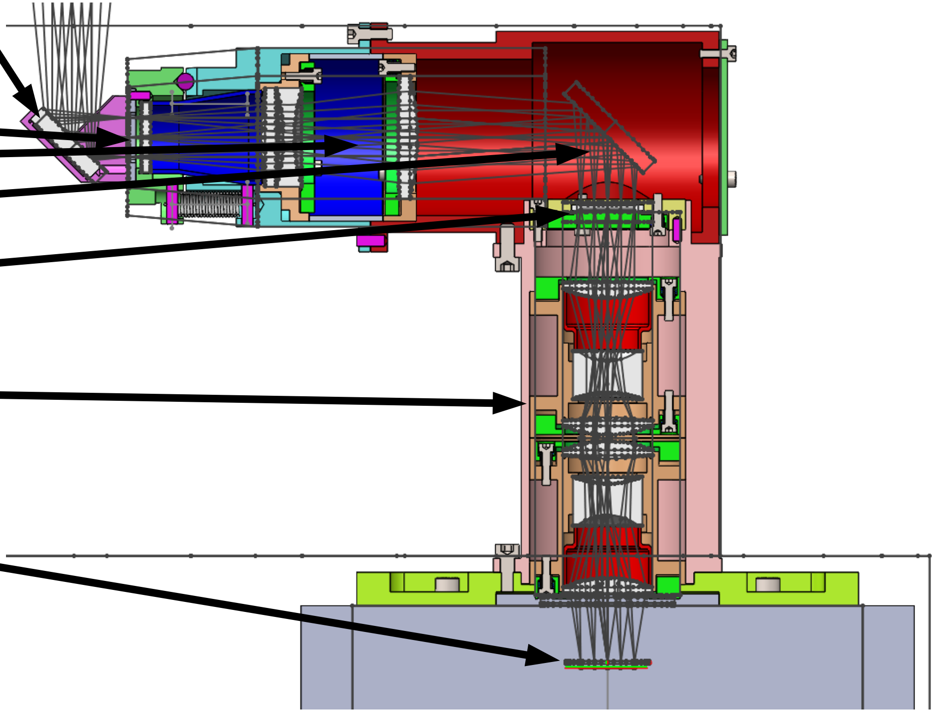
- 6 (or 8) identical channels:
  - IPAG provides them also for HARMONI





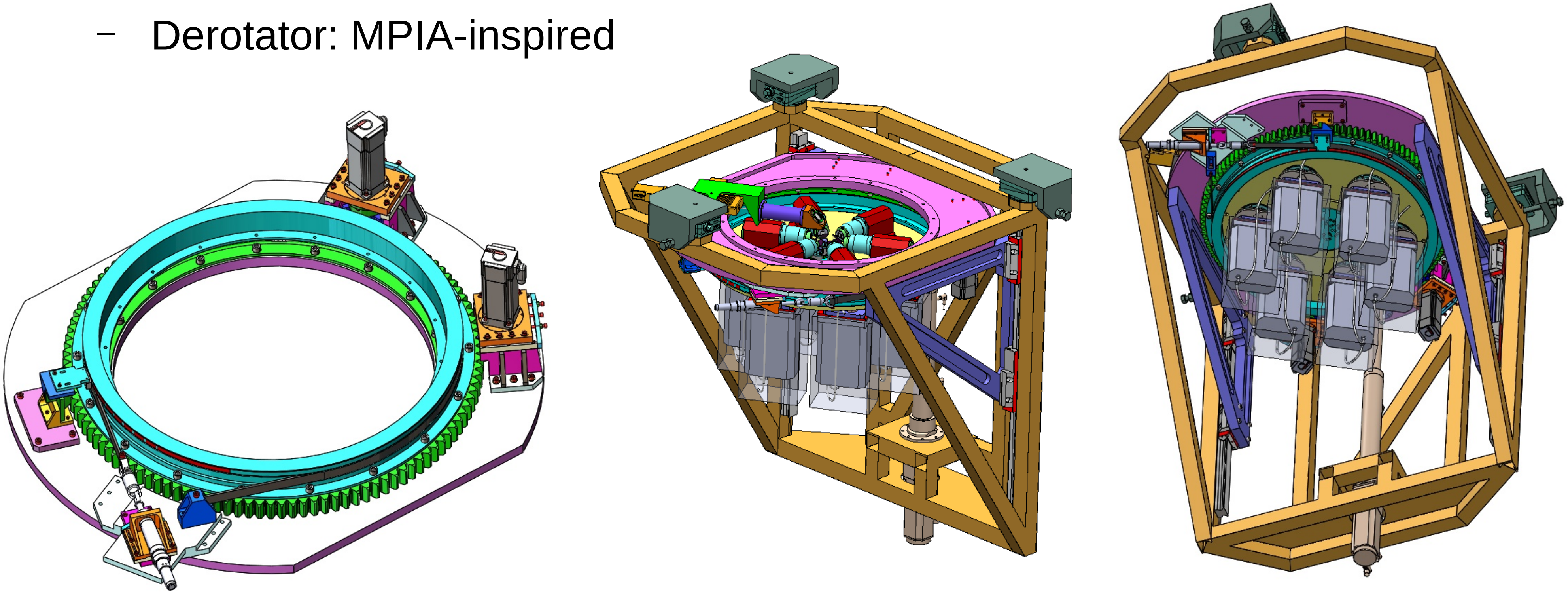
LGS-WFS Design

- 6 (or 8) identical channels:
  - Pick-off mirror (piezo, pupil steering mirror)
  - Field-stop
  - Collimator
  - Fix 45° mirror
  - Lenslet array
  - Relay optics
  - Detector



LGS-WFS Design

- 6 (or 8) identical channels:
  - Derotator: MPIA-inspired



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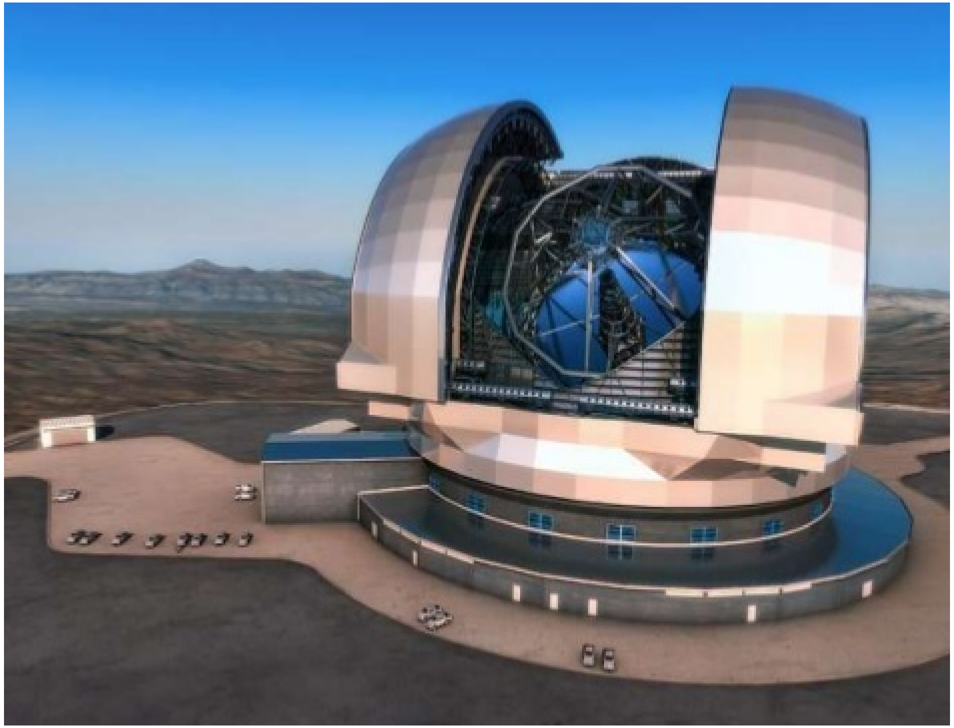

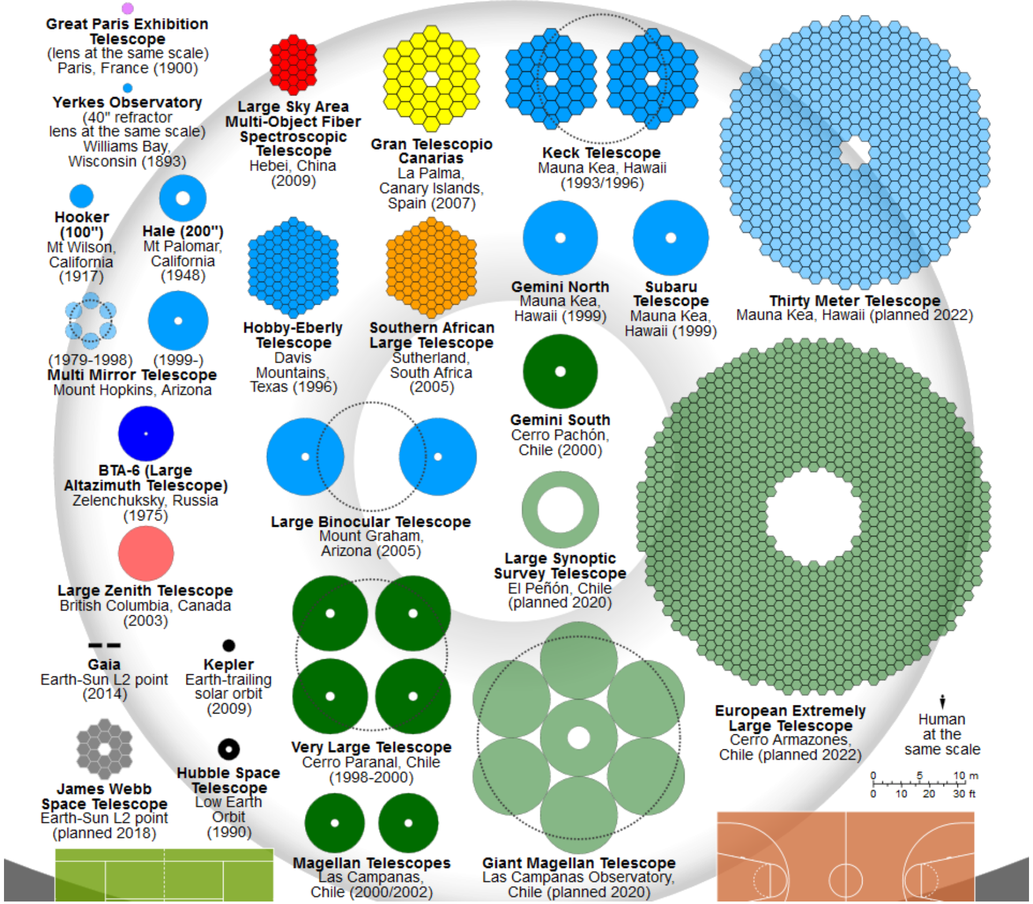

Appendix