Optical Infrared Instrumentation at INAF

V.N. Karazin Kharkiv National University – INAF Bilateral Workshop on Astrophysics

23 March 2018

Outline

- INAf technological approach
- R&D few examples
- Instrumentation development few examples

INAF Instrumentation and technology approach

- Technology R & D
  - Improve scientific performance for next generation instrumentation
  - Enable new Instrumentation Ideas/ architectures
- Instrumentation design and Integration
  - Implement Edge-technology to maximise the Instrument performances
  - Improve the know how and the core competences

Core competences Vs Technological Transfer

- In house Development
  - Increase the Institute core competences
  - Allow «flexible» evolution of the projects
  - Usually Cheapest
- Industry outsourced Development
  - Stronger Product Quality Assurance
  - Usually more clear develoment path
- Hybrid solution
  - Combines the core competencies of the Insitute with the Industry Quality Assurance
  - Easy the Technology transfer

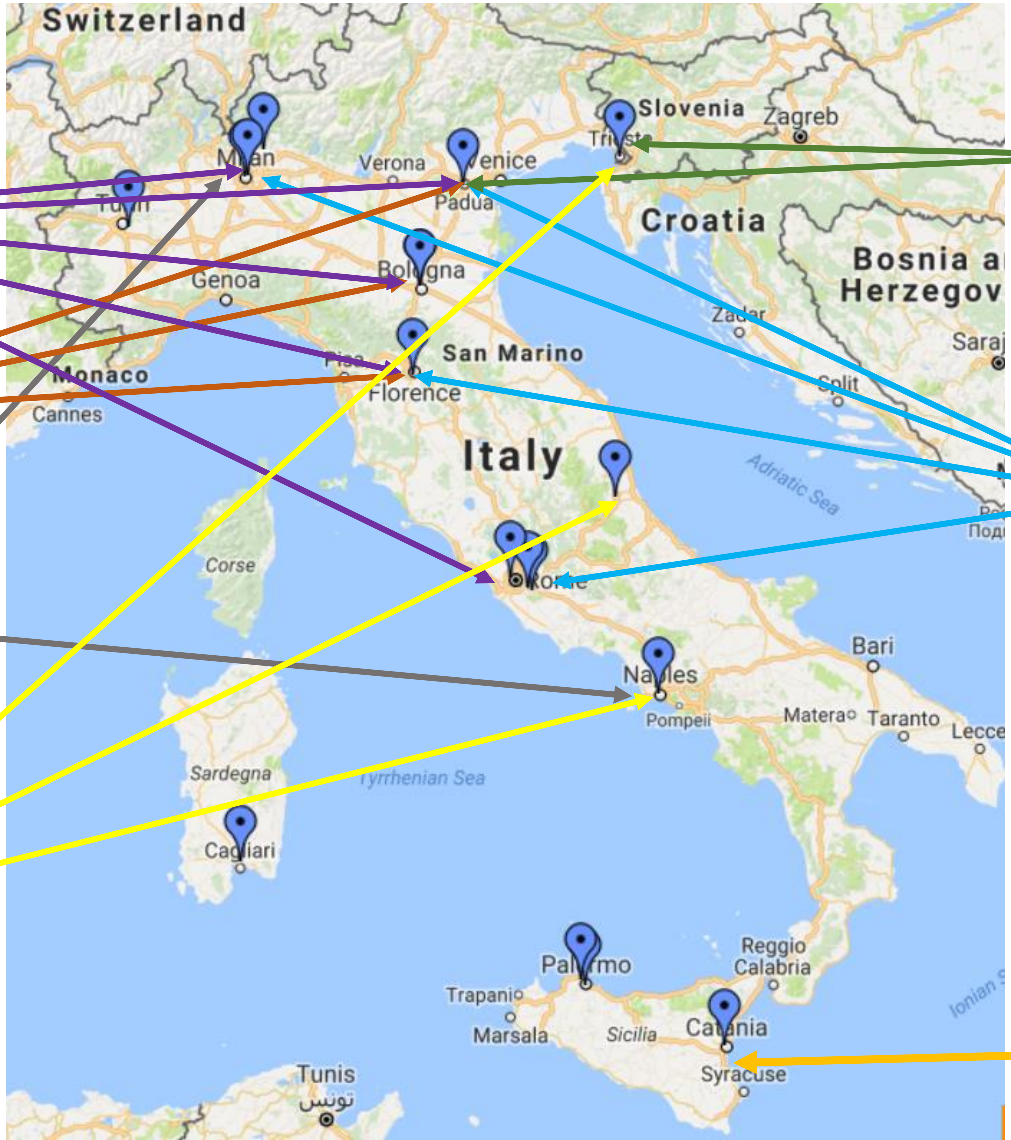
Main Competence distributionin INAF

AIVT activity

Adaptive optics

Mechanical Design

Electrical Design

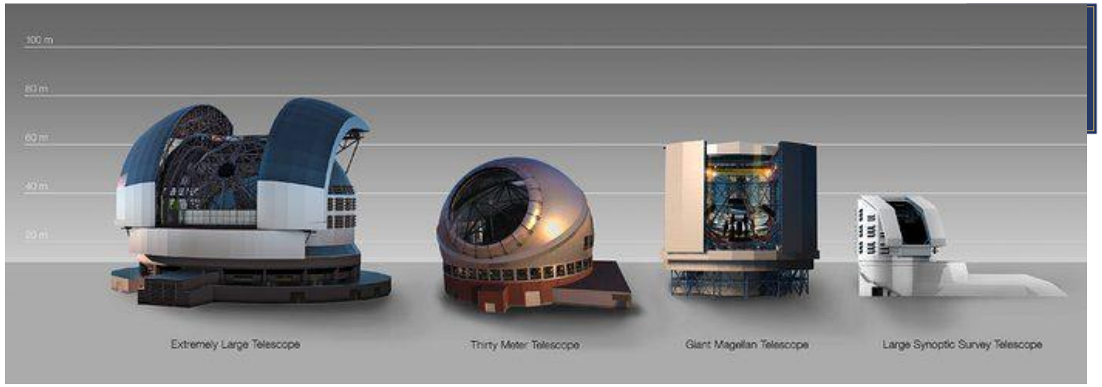


Software Design

Optical Design

Detectors

Why ELT era require R&D



- the need to produce an enormous number of hexagonal mirror segments to cover the collecting area of around 1400 square metres.
- the active correction of the mirrors to compensate for the mechanical deformation caused by the enormous weight;
- adaptive correction to obtain a real gain in terms of spatial resolution;
- the dimensions of the instruments that start to take on enormous proportions, especially given the current limits on the maximum possible dimensions of optical elements such as lenses, mirrors, reticules and prisms;
- the increase in the detecting area with consequent construction of ever larger detector mosaics.

Instrument Oriented R&D

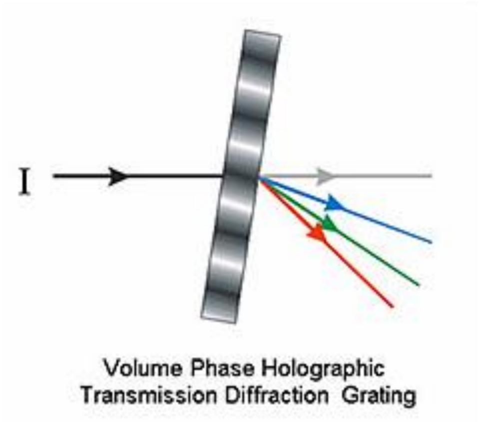
- Innovative Adaptive optics
  - New wavefront sensors
  - Innovative AO architectures
- New materials for Astronomy
- New optical manufacturing technologies
- Innovative integration techinques
- …

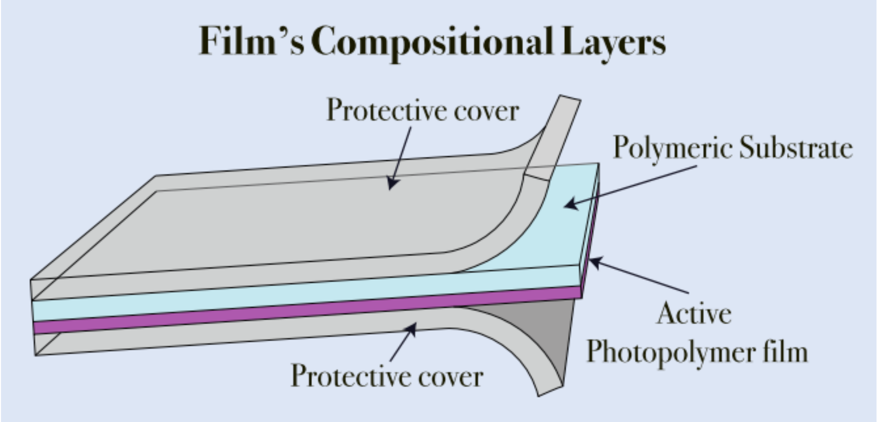
Adaptive Optics R&D

- The development of technologies for thin, deformable mirrors, with electromagnetic actuators, including the development of the associated optical components and metrology, innovative moulding technology (hot slumping) for thin shells, capacitive sensors and actuators, electronics and control systems.
- The development of new kinds of wavefront sensors, able to observe both natural and artificial reference stars (also in an unconventional way), deriving information not traditionally produced, such as the three dimensional structure of turbulence or phase shift between the various sectors of the main mirror.
- The optimisation of the observing strategy to maximise the scientific return of instruments served by adaptive optics, encouraging meetings, working groups and workshops both at the national and international level.

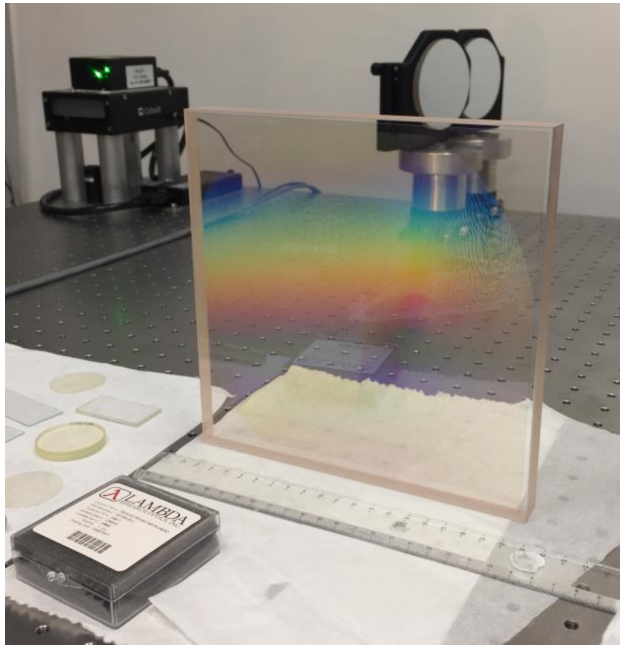
Volume Phase Holographic Gratings

Diffraction thanks to a periodic refractive index modulation.





Innovative holographic materials are used to make VPHGs up to 20 cm in diameter;
Nine VPHGs based on such new materials are mounted on astronomical spectrographs



Features:

- **Large peak efficiency (>90%)**
- Tunable efficiency (Super Blaze)
- Large size (up to 30x60 cm)
- **Large dispersion (up to 6000 l/mm)**
- Robust, AR coating, complex structure
- Work very well in Vis-NIR

In general, we are interested and we have a broad expertise in dispersing elements for astronomy:

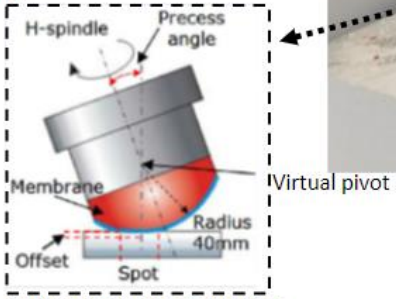
Optical Manufacturing Techniques

7-axis Robotic System

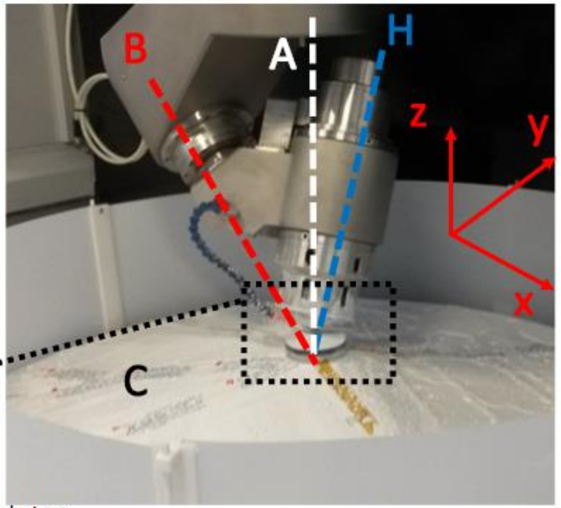
- Axes: X, Y, Z, C table, H tool spindle, A, B rotations.
- The tool is a spherical and inflated rubber membrane, named bonnet.

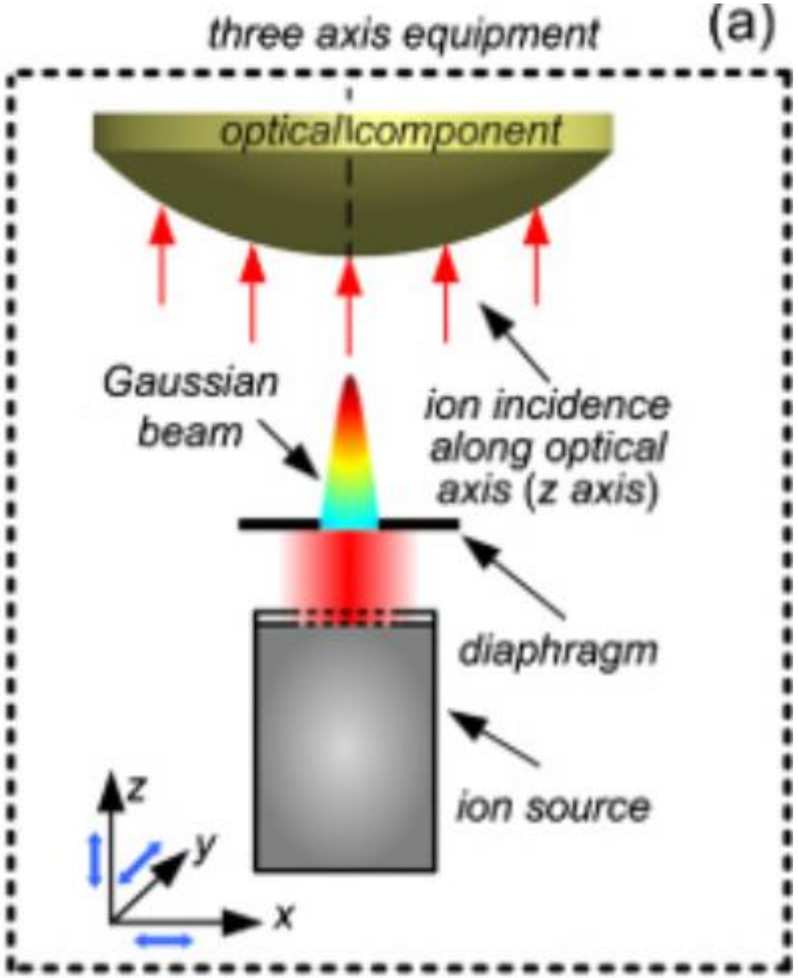
Bonnet tool

- H axis is inclined to the surface's local normal (by A, B rotations), defining the precess angle.
- A, B axes cross H axis at the center of curvature of the bonnet.

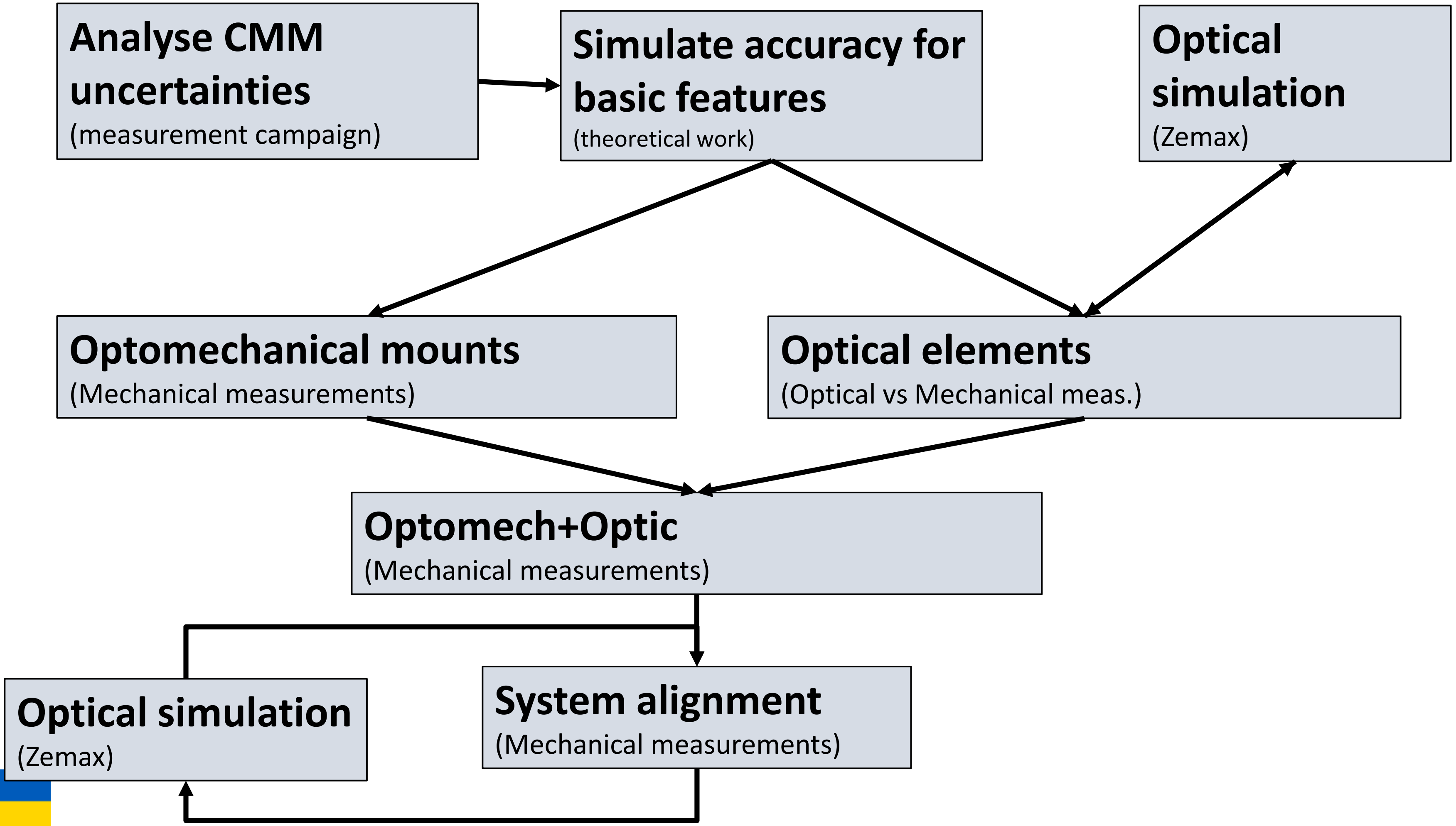


Credit: A. Beaucamp et al. (2013)





Mechaniacal Metrology based alignment techinque



Working Range [m]	Single point repeatability [µm]
60-80	8
1.8	24
0.9*0.8*1.5	1.8

Completed and delivered Instrumentations

Development together with external consortia

Together with external consortia ESO was responsible for the definition and contributed to the design, construction and implementation at the observatories of the following instruments and facilities:

For Paranal

AMBER (VLTI)

FLAMES (VLT)

FORS1+2 (VLT; FORS1 retired)

KMOS (VLT)

LGSF (VLT)

MIDI (VLTI)

MUSE (VLT)

NACO (VLT)

OmegaCAM (VST)

SINFONI (VLT)

SPHERE (VLT)

VIMOS (VLT)

VISIR (VLT)

X-Shooter (VLT)

For La Silla

FEROS (2.2m)

HARPS (3.6m)

WFI (2.2m)

Inhouse development

The following operational instruments have been built under the of ESO:

For Paranal

CRIRES (VLT)

HAWK-I (VLT)

ISAAC (VLT)

UVES (VLT)

For La Silla

CES (3.6m; retired)

EFOSC2 (NTT, formerly 3.6m; retired)

EMMI (NTT; retired)

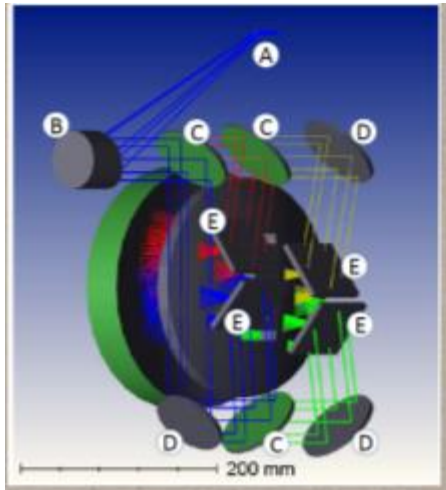
SOFI (NTT)

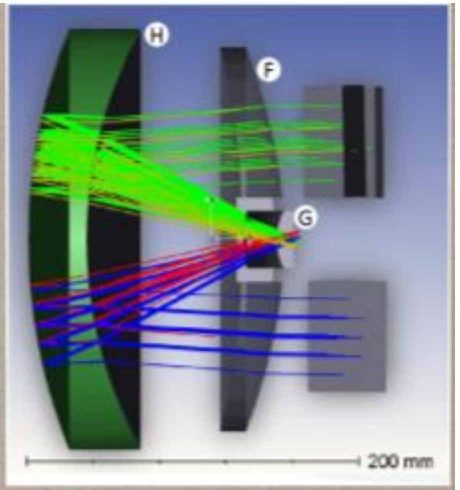
SUSI2 (NTT; retired)

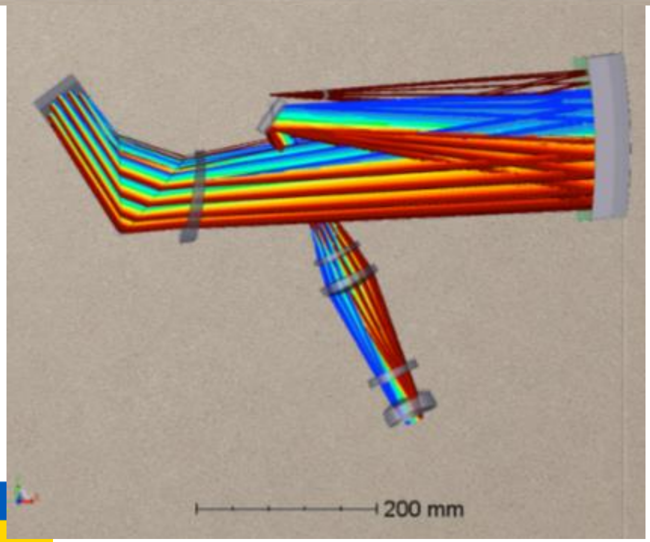
Instrument under development

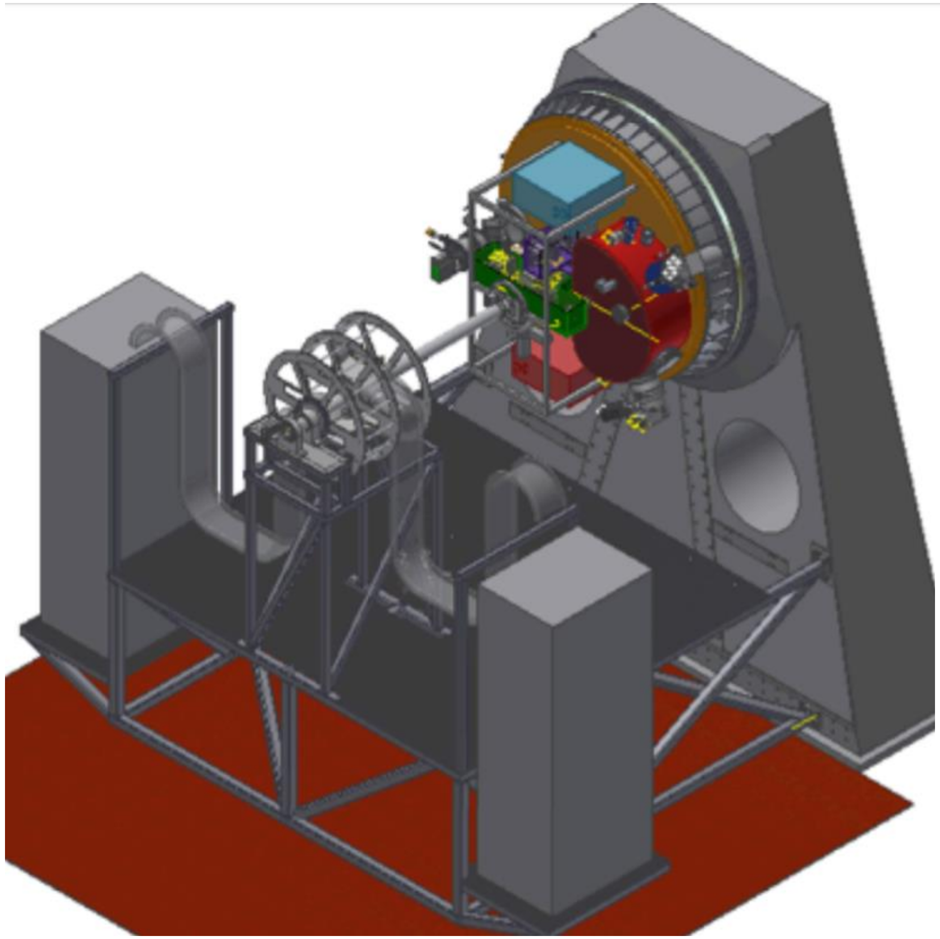
Design Phase	Manufacture, Assembly Integration and Testing	Commissioning	Upgrades	Infrastructure
ERIS (VLT)	MATISSE (VLTI)		VISIR (VLT)	AOF-GALACSI (MUSE)
MOONS (VLT)	GRAVITY (VLTI)		CRIRES+ (VLT)	AOF-GRAAL (HAWK-I)
4MOST (VISTA)	ESPRESSO (VLT)			AOF-DSM
				AOF-4LGSF
				VLTI

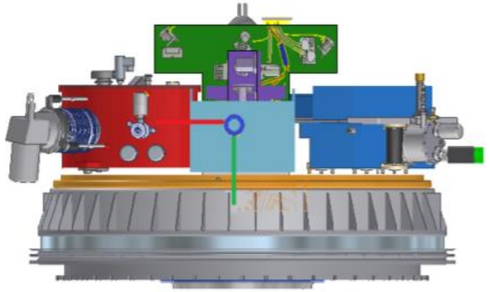
SOXS snapshots

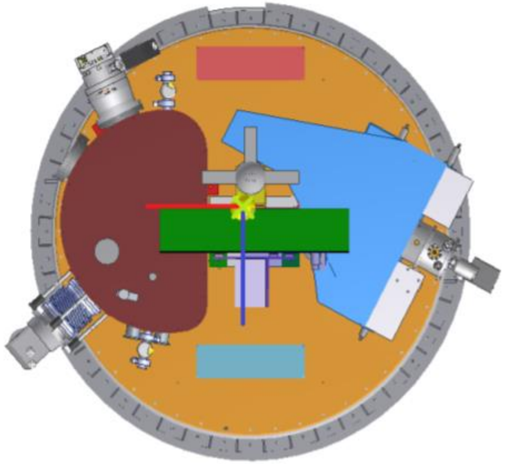




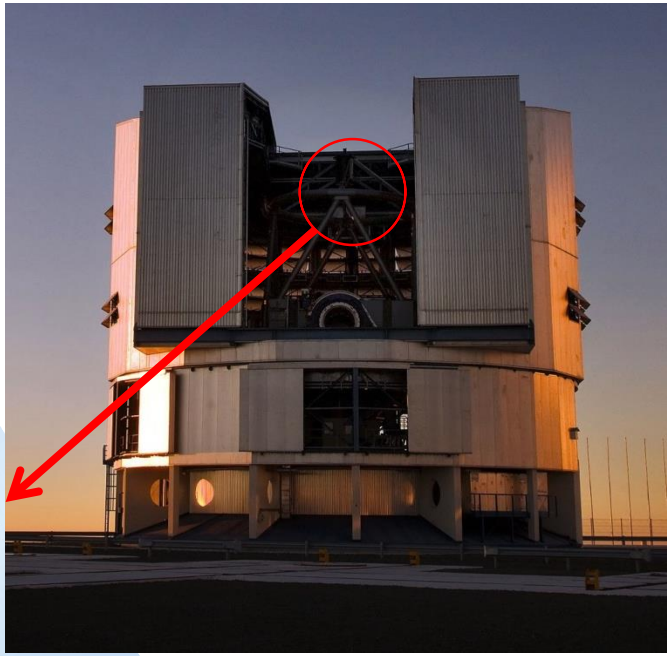








VLT: DSM, the UT4 Deformable Mirror



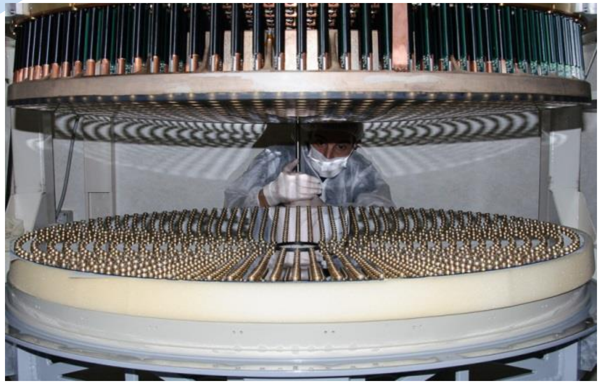
Adaptive Secondary mirror

Replacing the Dornier rigid Secondary of UT4

- Shape: Convex, Aspheric
- OD: 1.2 m
- Thin Shell thickness: 2mm
- # actuators: 1170
- Settling time: < 0.5 ms

‘Evolution’ of LBT AdSecondary:

- Dynamic FeedForward (2x faster)
- New design of Ref Body, actuators
- *Antiseismic*



DSM project

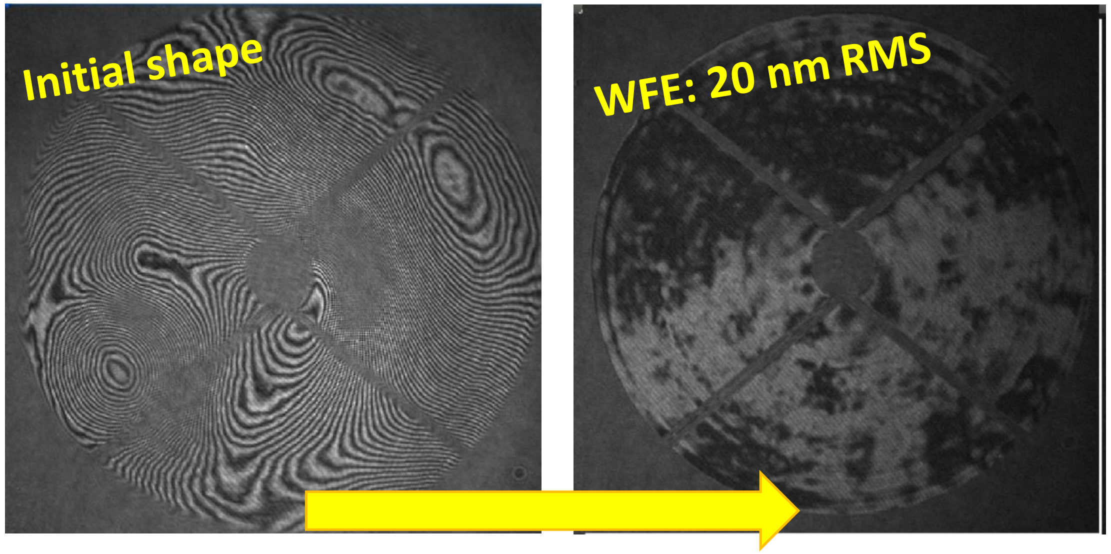
- **Partners**
  - **ADOPTICA** as prime-contractor (companies consortium, MG+ADS)
  - **INAF-OAA** as:
    - Independent consultant/reviewer
    - sub-contractor for Optical Characterization and Verification

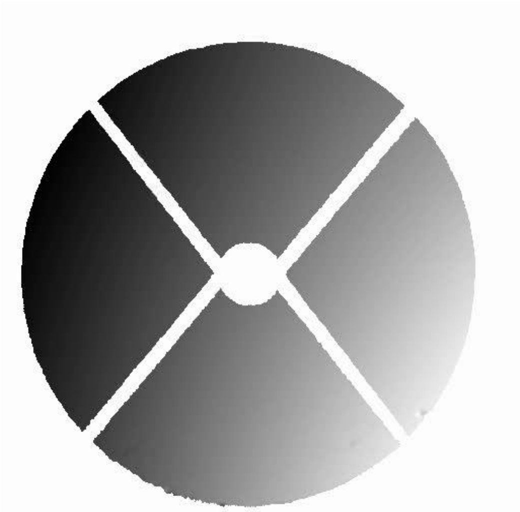
- **INAF Tasks:**
  - Consultant (AO expertise)
  - Reviewer for TAE1
  - Subcontractor: optical test @ ESO on ASSIST test facility

Optical test of the DSM on ASSIST

The Optical Calibration of a defomable mirror consists in:

1. Calibrate the actuator **influence functions**;
2. Compute the actuator commands to produce a **flat optical shape**
3. Calibrate **the internal metrology** to allow open loop, large stroke commands (chopping, field stabilization, e.g.)





DSM Influence Functions

VLT: ERIS instrument

ERIS, the Enhanced Resolution Imager and Spectrograph, is an instrument for the Cassegrain focus of UT4 at the VLT. It is made of:

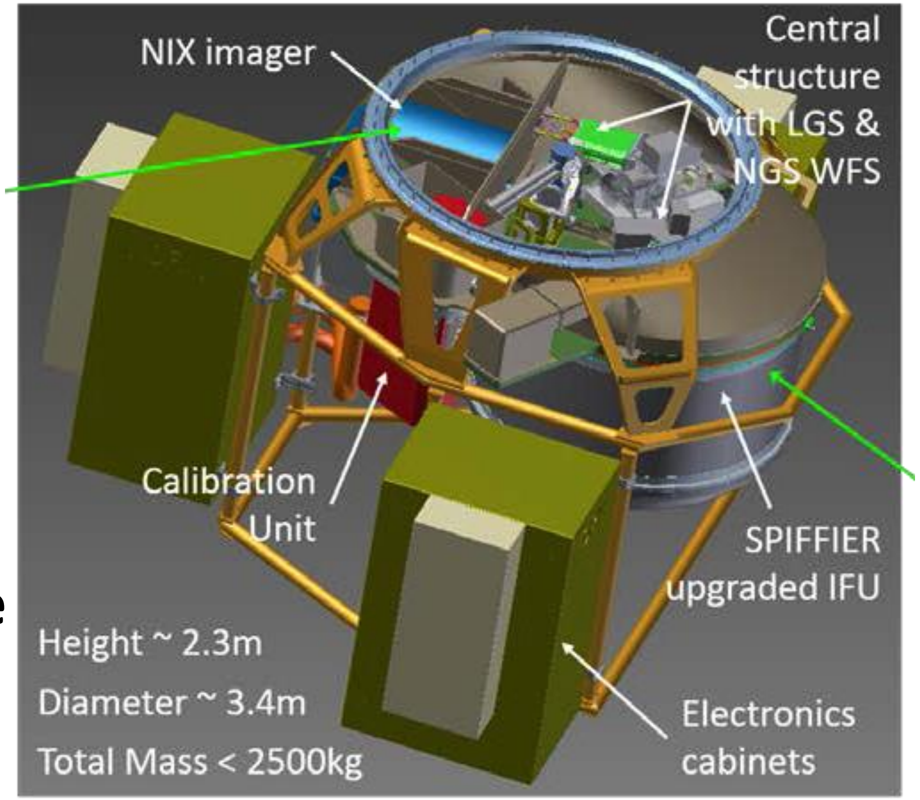
two **science instruments**:

- **NIX**: infrared imager providing diffraction limited imaging, Sparse Aperture Masking (SAM) and pupil plane coronagraphy capabilities from **1 to 5 µm**.

- **SPIFFIER** (Spectrometer for Infrared Faint Field Imaging with Enhanced Resolution): near-infrared (**1.0-2.5 µm**) integral field spectrograph (upgraded version of SPIFFI)

- An **Adaptive optics module** with single conjugated LGS and NGS modes, using AOF DSM and LGS facilities

- A **calibration Unit** (CU).



ERIS will integrate, substitute and enhance the functionalities of NACO and SINFONI

ERIS Consortium

Cost: 6M€ + 115FTE

Country	***Institute***	***Lead roles***
Germany	MPE	Project office, systems engineering, central structure, SPIFFI upgrade, SPIFFIER
Italy	INAF-Arcetri	Adaptive optics, warm optics
	INAF-Teramo	Calibration unit
	INAF-Padova	Instrument control SW
UK	ATC	NIX (including data pipeline)
Switzerland	ETH-Zurich	NIX filters, masks, wheel mechanisms
ESO		Handling tool, guider arm upgrade, detector controllers, RTC/SPARTA

VLT: ESPRESSO instrument

The main scientific drivers for ESPRESSO are:

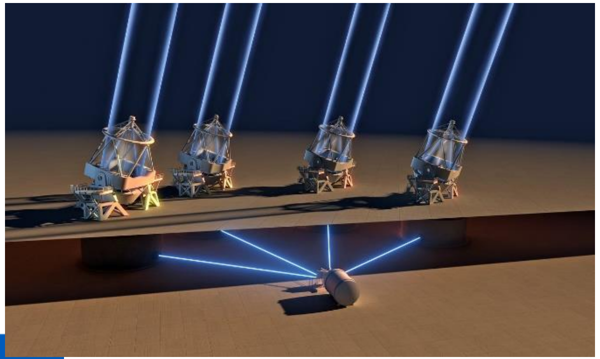
•the measurement of high precision radial velocities of solar type stars for search for rocky planets

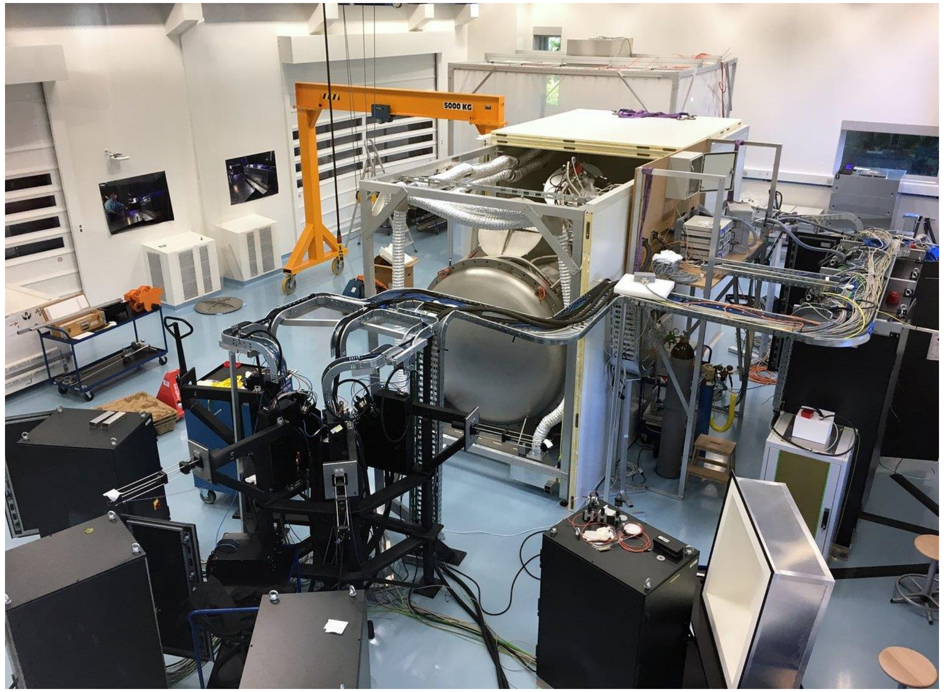
•the measurement of the variation of the physical constants

•the analysis of the chemical composition of stars in nearby galaxies

These science cases require an efficient, high-resolution, extremely stable and accurate spectrograph.

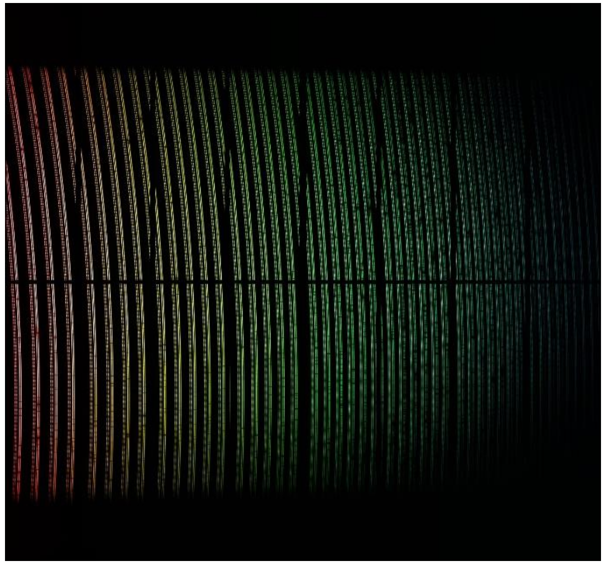
Requirement	Standard 1-UT	4-UT	Very-High Res 1-UT
Wavelength Range	380-686 nm	380-686 nm	380-686 nm
Resolving Power	120.000	30.000	220.000
Aperture on Sky	1.0 arcsec	4x1.0 arcsec	0.5 arcsec
Sampling (average)	3.3 pixels	4.0 pixels (binned x2)	2.1 pixels
Spatial Sampling	6.9 pixels	4.0 pixels (binned x2)	3.5 pixels
Simultaneous reference	Yes (no sky)	Yes (no sky)	Yes (no sky)
Sky subtraction	Yes (no sim. ref.)	Yes (no sim. ref.)	Yes (no sim. ref.)
Total Efficiency	>10% at peak	>10% at peak	> 7% at peak
Instrumental RV precision (requirement)	<10 cm/sec	<=5 m/sec	<=5 m/sec





Espresso Consortium

Cost: 13M€ + 130FTE

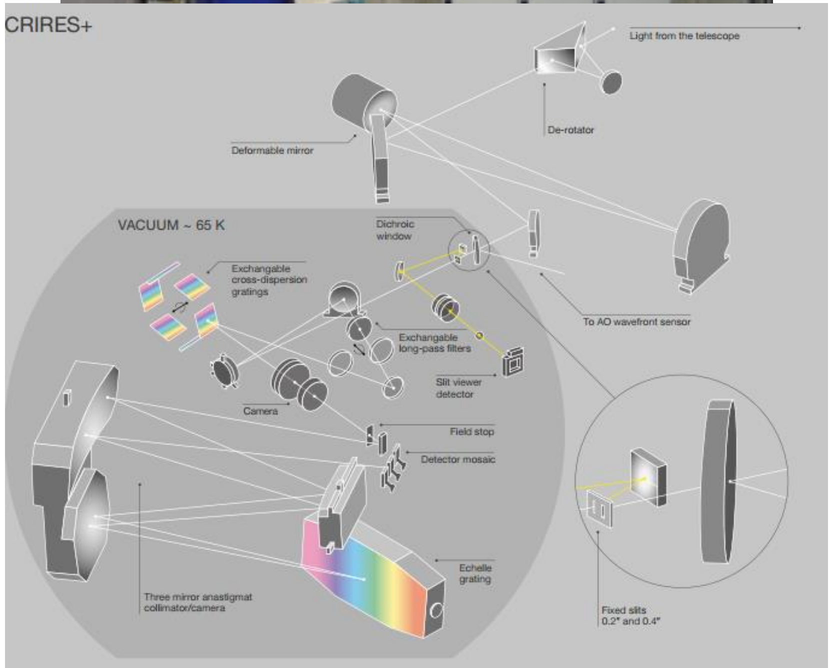


Centro de Astrofísica da Universidade do Porto
Universidade de Lisboa, CAAUL and LOLS
INAF, Osservatorio Astronomico di Trieste
INAF, Osservatorio Astronomico di Brera
Observatory of the University of Geneva
Physics Institute, University of Bern
Instituto de Astrofísica de Canarias
European Southern Observatory

Astronomical Observatory	University of Geneva	OGE	Switzerland
Physics Institute	University of Bern	SRPS-Bern	Switzerland
Instituto de Astrofísica de Canarias	Tenerife	IAC	Spain
Osservatorio di Trieste		INAF-OATS	Italy
Osservatorio di Brera		INAF-Brera	Italy
Centro de Astrofisica	Universidade do Porto	CAUP	Portugal
Facultade de Ciencias	Universidade de Lisboa	FCUL-CAAUL	Portugal

VLT: CRIRES+ instrument

- Transform CRIRES into an echelle spectrograph to increase the wavelength range that is covered simultaneously by a factor of ten.
- In addition, a new detector focal plane array of three Hawaii 2RG detectors with a 5.3 µm cut-off wavelength will replace the existing detectors
- a new spectropolarimetric unit will be added and the calibration system will be enhanced.



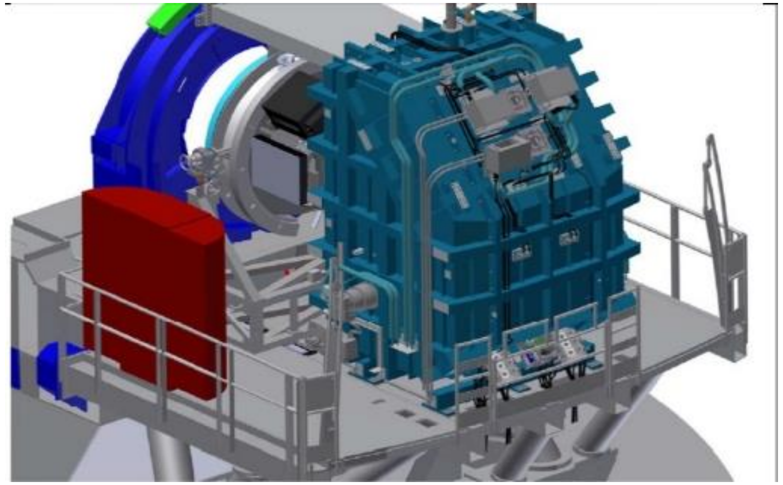
VLT: CRIRES+ consortium

The CRIRES+ consortium:

- ESO
- Thüringer Landessternwarte Tautenburg (TLS)
- Institute for Astrophysics Göttingen (IAG)
- INAF Arcetri Astrophysical Observatory (Florence)
- Uppsala Universitet

VLT: Moons instrument

Parameter	Specifications
Telescope	VLT
Field of View	500 arcmin^2
Multiplex	1000 objects, with possibility to deploy fibre pairs (500 obj+500 sky)
Sky-projected diameter of each fibre	1.05 arcsec
Close packaging	At least two fibres within 10 arcsec
Observing modes	medium resolution (MR) and high resolution (HR)
Simultaneous λ-coverage in MR	0.64μm - 1.8μm
Resolving power in MR	R ~ 4,000 – 6,000
Simultaneous λ-coverage in HR	[0.76μm – 0.9μm] + [1.177μm – 1.268μm] + [1.521μm – 1.635μm]
Resolving power in HR	R~9,000 R~20,000 R~20,000



VLT: Moons consortium

MOONS
Multi Object Optical and Near-infrared Spectrograph

AIUC
CENTRO DE ASTRO-INGENIERIA UC

CAAUL
FACULDADE DE CIÊNCIAS

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

INAF ISTITUTO NAZIONALE DI ASTROFISICA

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

l'Observatoire de Paris
GEPI

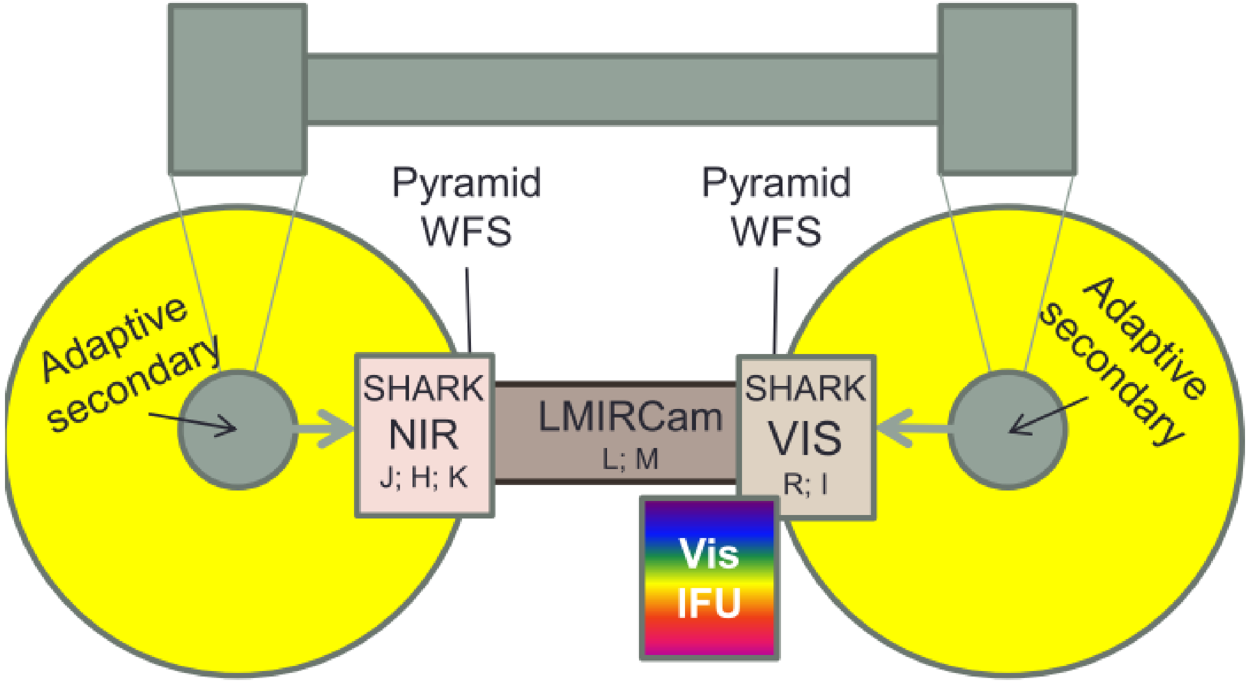
ESO

UNIVERSITY OF CAMBRIDGE

Science & Technology Facilities Council
UK Astronomy Technology Centre

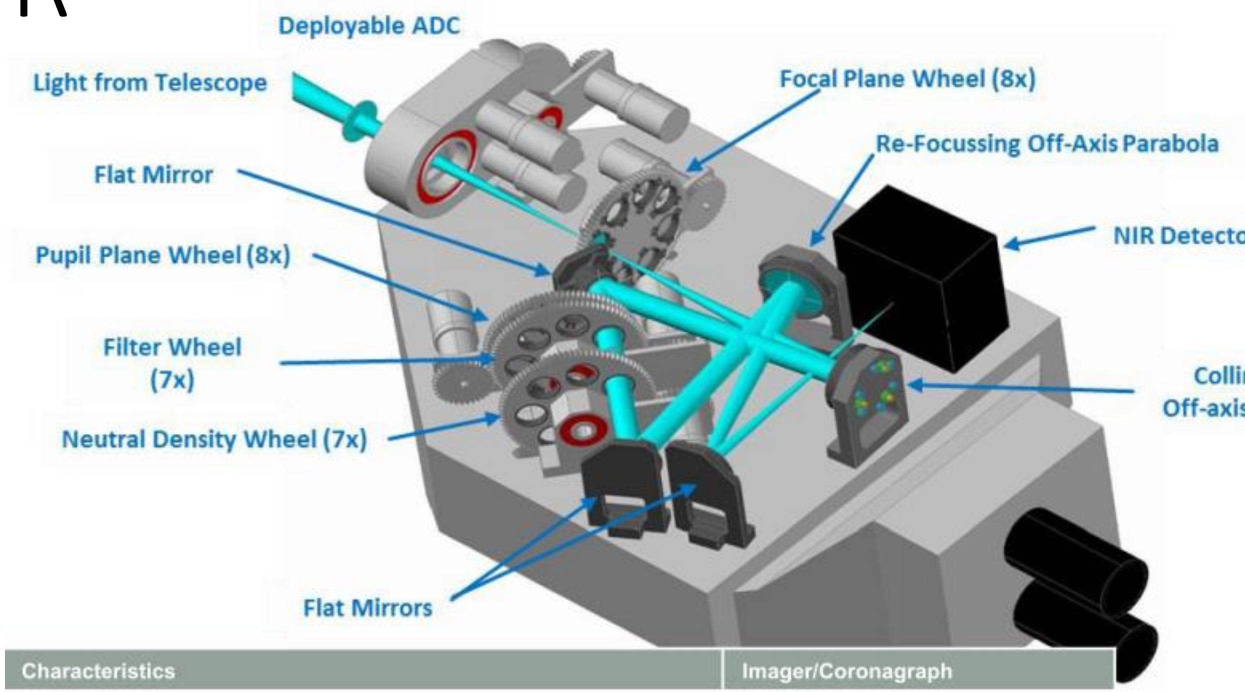
LBT Shark NIR

- In fact, SHARK basic features are:
- NIR Coro-Camera (J,H,K)
- VIS Coro-Camera (R,I)
- VIS Spectrograph

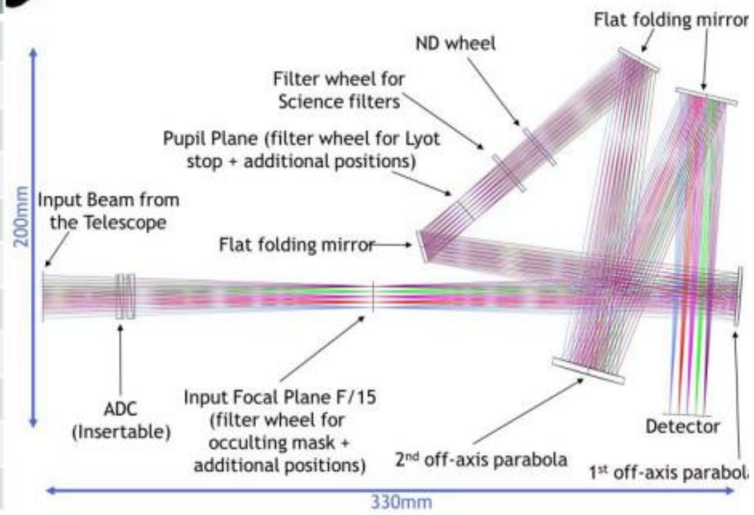


LBT Shark NIR

- High resolution fast imager with FLAO@LBT
- Bynocular AO from 600 ÷ 900 and 900 ÷2200 nm
- Experimental focal plane for coronagraph and…
- Synchronous recording of wave-front residual

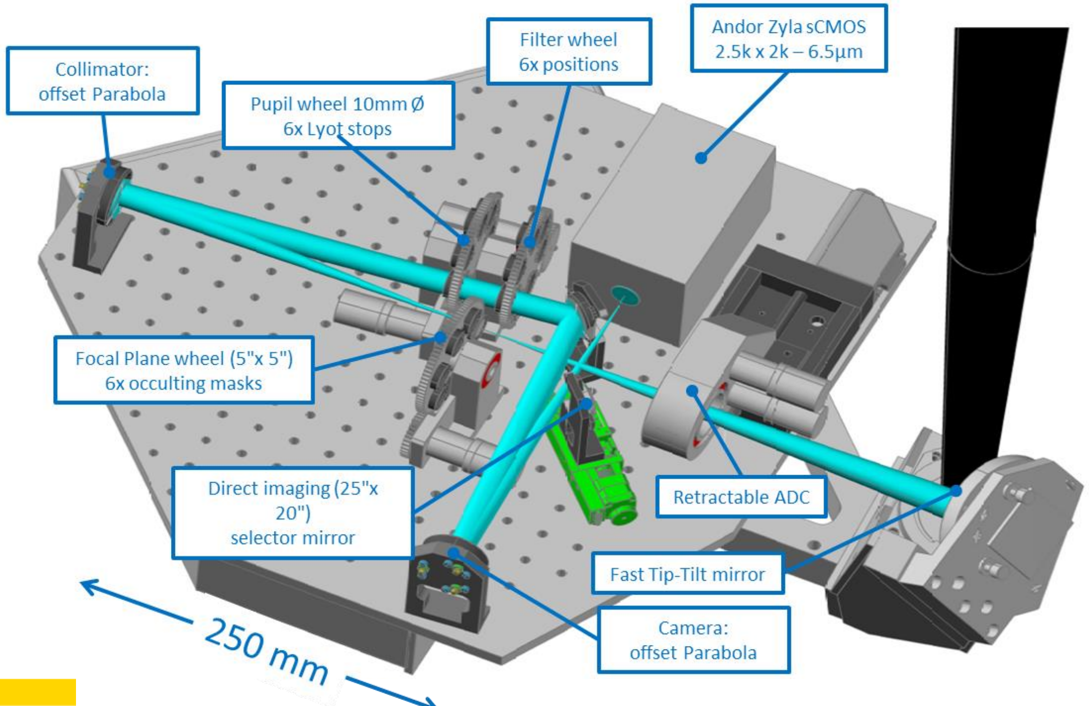


Characteristics	Imager/Coronagraph
Field of View [arcsec]	19.2 x 19.2
Wavelength Range [µm]	1.1-2.4
Sampling J Band [marcsec/pix]	19
E.E. @ 37 mas (J Band Diffraction Limit PSF)	>83%
Intrinsic Optical Quality (0°-25° Zenithal Distance - NO ADC) [SR]	>99.8%
Intrinsic Optical Quality (30° Zenithal Distance with ADC) [SR]	>97.8%
Intrinsic Optical Quality (45° Zenithal Distance with ADC) [SR]	>97.7%
Coronagraph type	Lyot (+ TBD)
Filters	TBD (J,H,K + Narrow Bands)
Polarimetric filters	TBD
Long Slit + GRISM or VPh Spectroscopy	TBD



LBT Shark VIS

- High resolution fast imager with FLAO@LBT
- Bynocular AO from 600 ÷ 900 and 900 ÷2200 nm
- Experimental focal plane for coronagraph and…
- Synchronous recording of wave-front residual



SPECIFICATION

Direct Imager

- ✓ Field of view = (20x25)" or (8x10)"
- ✓ Sampling 4÷10 mas /pixel
- ✓ ADC bandwidth 600 ÷ 900 nm

Coronagraph

- ✓ Field of view = (5x5)"
- ✓ Sampling 4÷10 mas /pixel
- ✓ Focal plane 6 x occulter
- ✓ Pupil plane 6 x stops/apodizers

Detector

- ✓ Fast sCMOS imager 1 e- r.o.n.
- ✓ Exposure 10e-4 ÷ 30 s

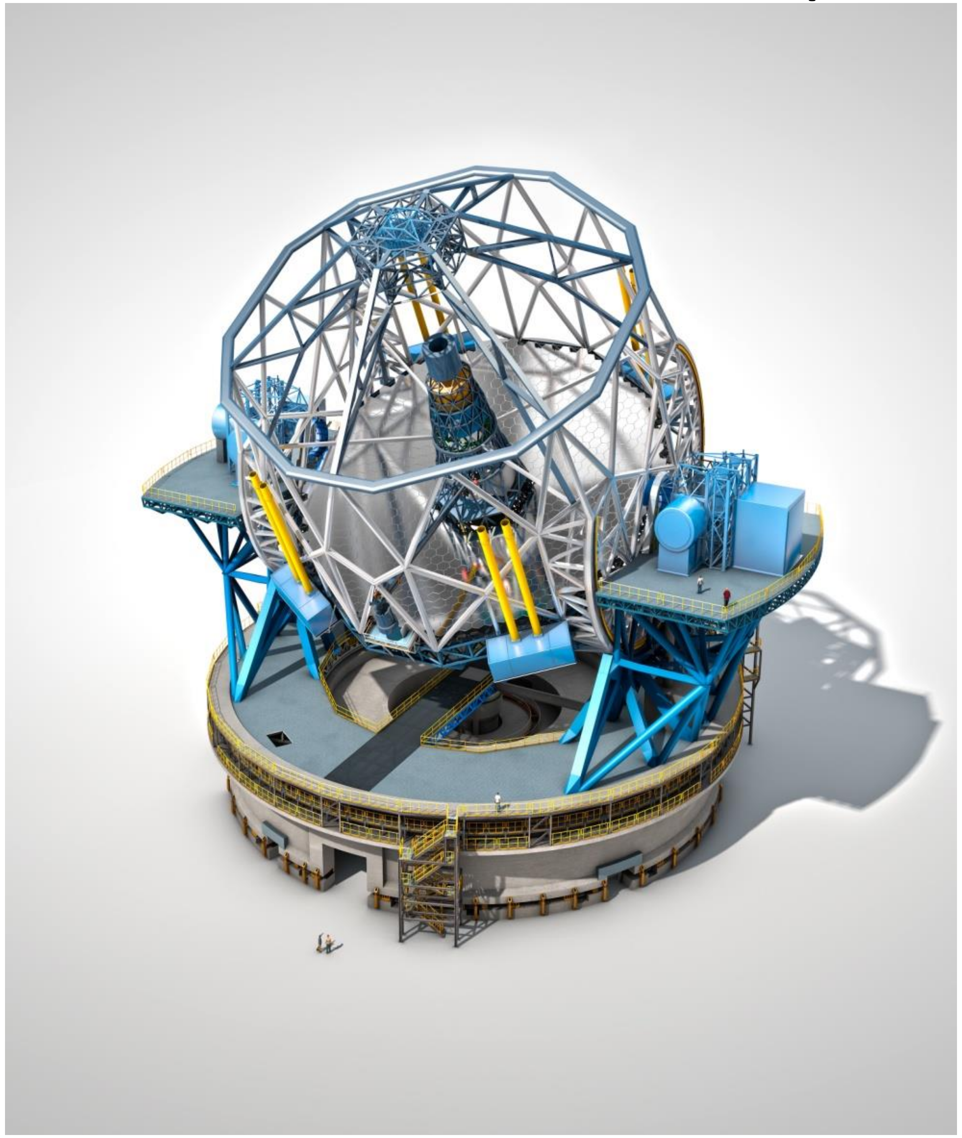
NTT Soxs

- Broad band spectrograph 350-2000 nm
- - R~4,500 (3,500-6,000)
- - Two arms (UV-VIS + NIR)
- - S/N~10 spectrum
- - 1 hr exposure for R~20
- - Acquisition camera to perform photometry ugrizY (3’x3’)

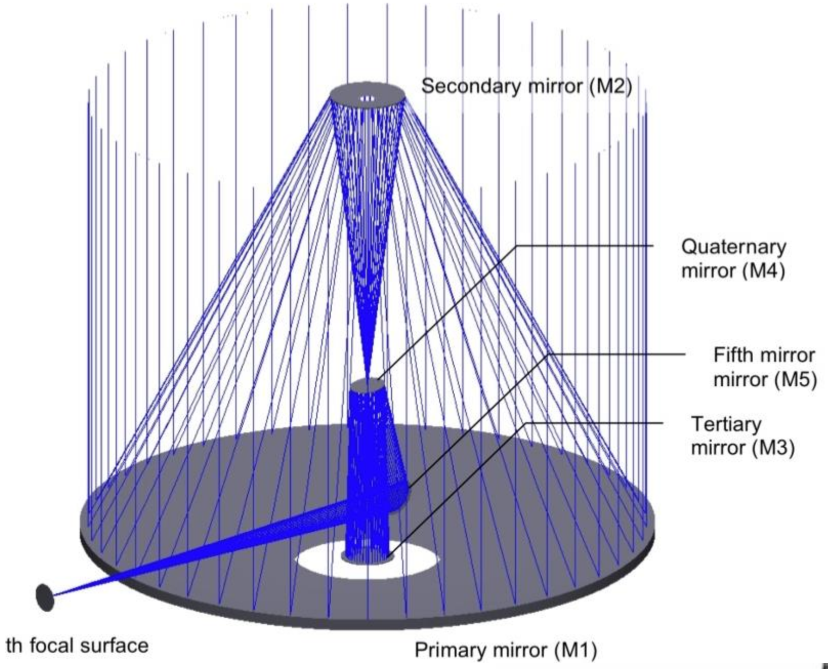
The E-ELT Project

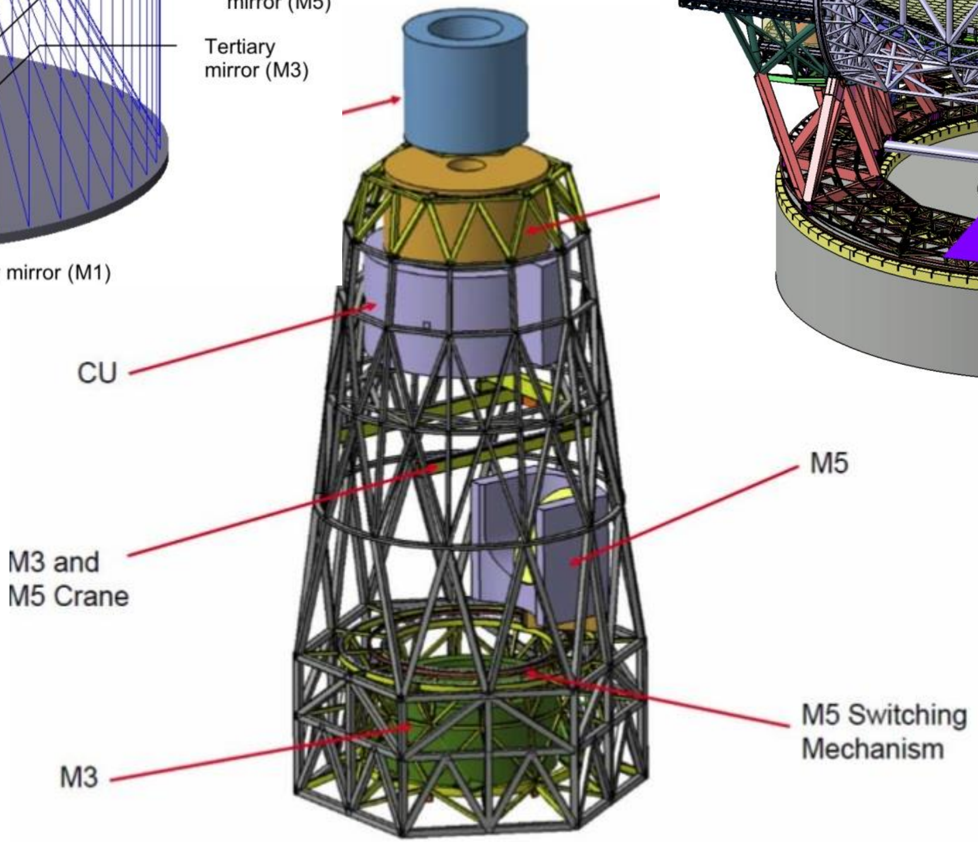
The Telescope

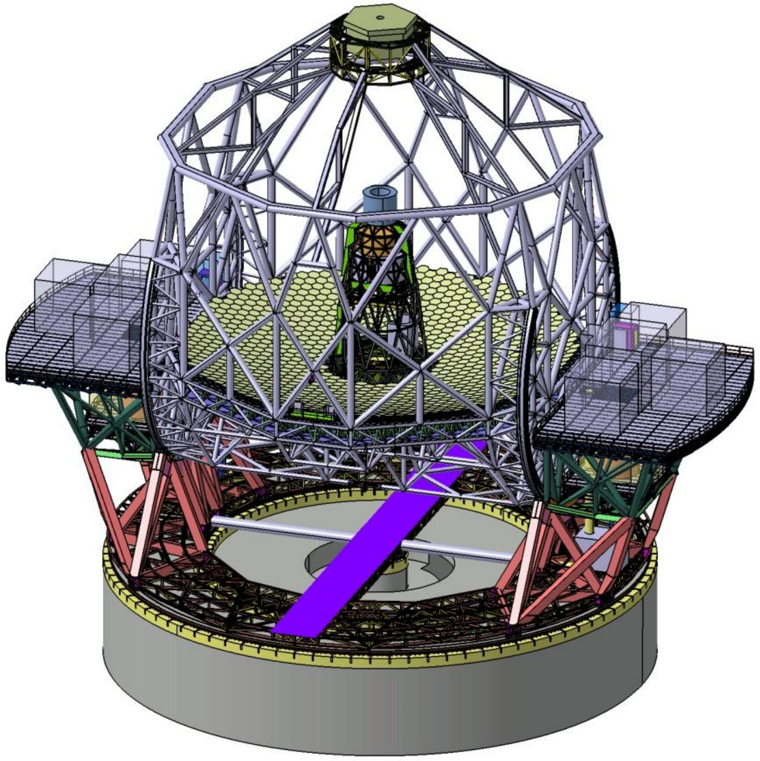
- **40-m class telescope optical-infrared** telescope
- **Segmented** primary mirror
- **Adaptive Optics** assisted telescope
- **Multi-LGSs** side launched
- Diffraction limited performance: **12mas@K-band** Wide field of view: 10 arcmin
- Mid-latitude site (Amazones/Chile)
- Fast instrument changes
- VLT level of operations efficiency.



The E-ELT Project
Adaptive telescope







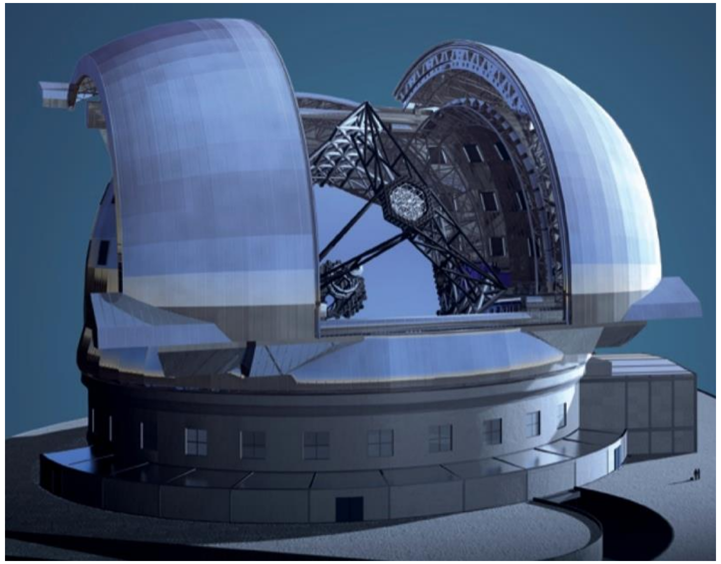
EELT: the M4 Deformable Mirror

- Optical Shape: flat
- OD: 2.34m, ID: 0.54m
- # segments: 6
- # actuators 5316
- on a triangular pattern (3.15cm pitch, 52.5 cm projected on M1)
- Settling time< 1ms
- Fitt. Error, median seeing:

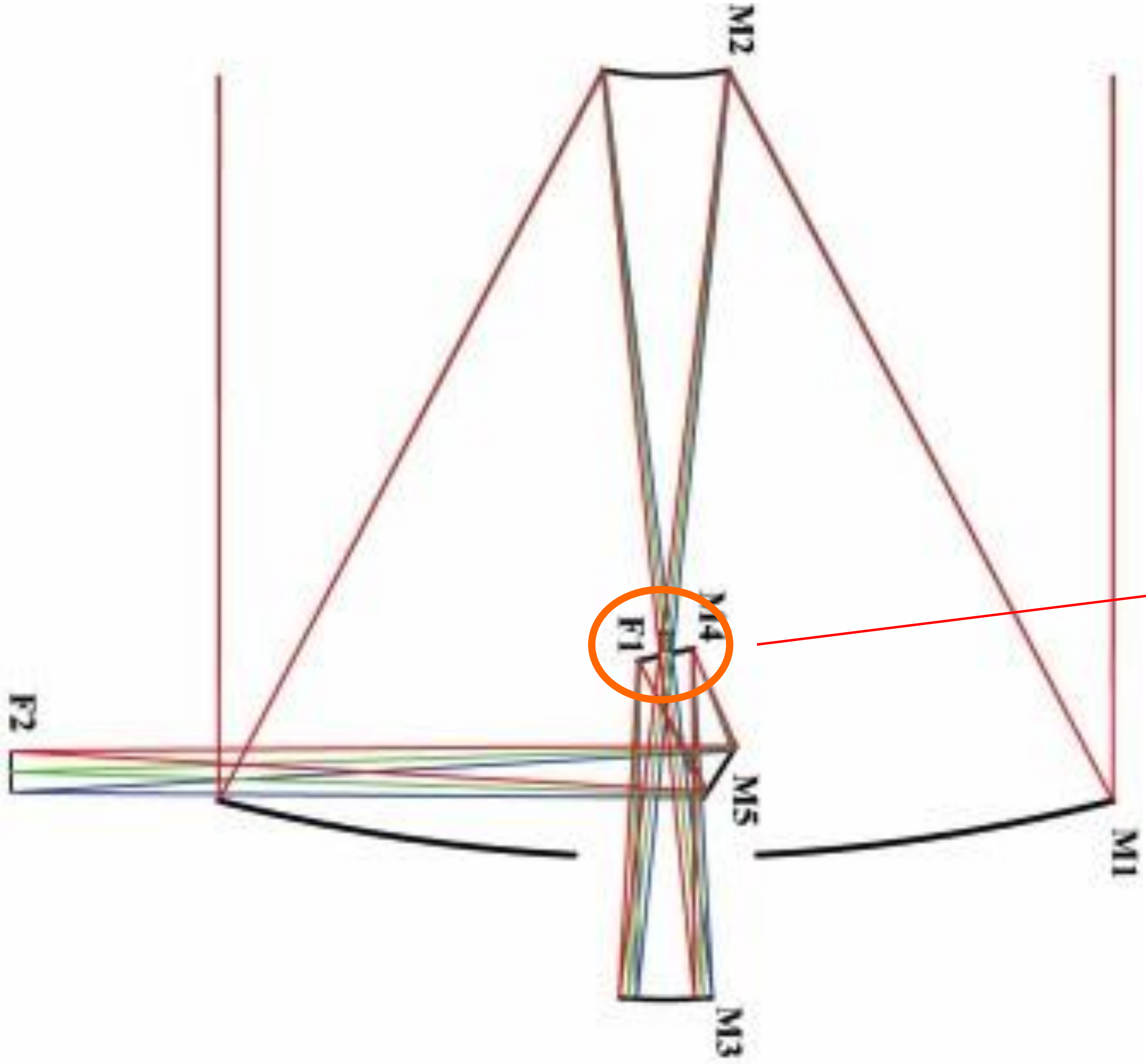
  145 nm WF
- Flattening spec:

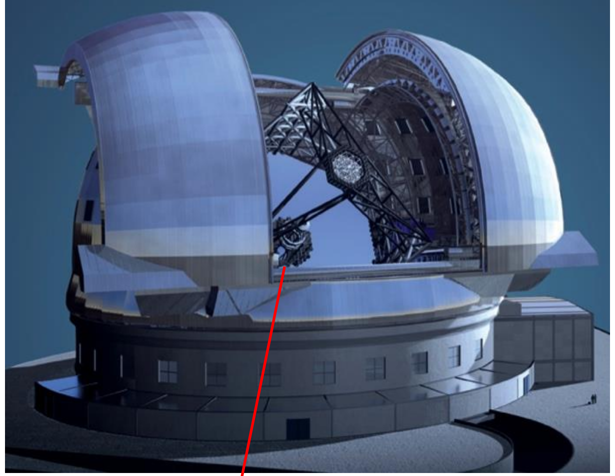
  20 nm WF
- Pupil position midway M4/M5:

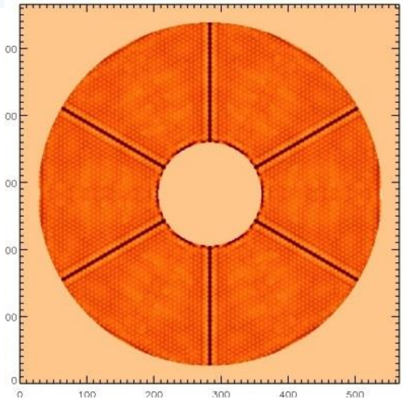
  → Optical area moves on M4, depending on field
- M5: Tip-Tilt only



E-ELT & M4







M4 project

- **Partners**
  - ADOPTICA as prime-contractor (companies consortium, MG+ADS)
  - **INAF** as sub-contractor

- **Allocated Budget:**
  - ~30M€ (tot)
  - ~ 1.3M€/7y (INAF)
  - 2.5FTE/y

- **INAF Team:**
  - Riccardi, Briguglio, Xompero (OAA)
  - Pariani (OAB)

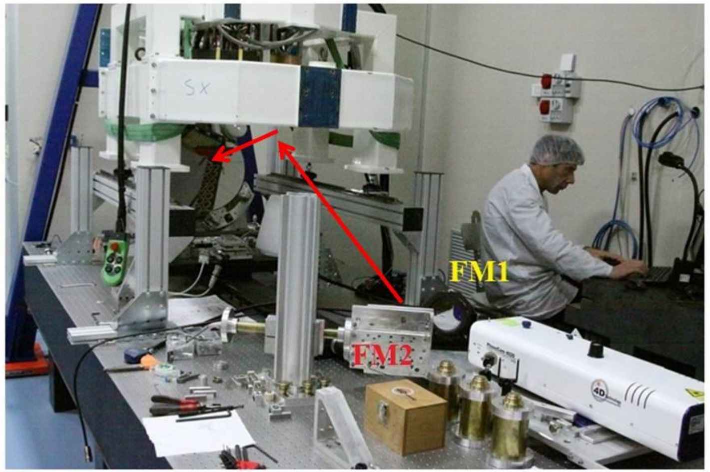
- **INAF Tasks:**
  - **AO expertise**
  - Error budget
  - **Optical design of Test Tower**
  - **Test plan and procedures**
  - Support of Tower integration and characterization
  - **M4 optical test** (2022)

Optical test of the M4 Demonstration prototype

M4DP:

- 2 segments, flat
- Size: 30cmx70cm (x2)
- #actuators: 2x111
- Testbench for:
    - Actuator ‘brick’ concept
    - New electronic design
    - New control strategy
- INAF responsible

for optical test



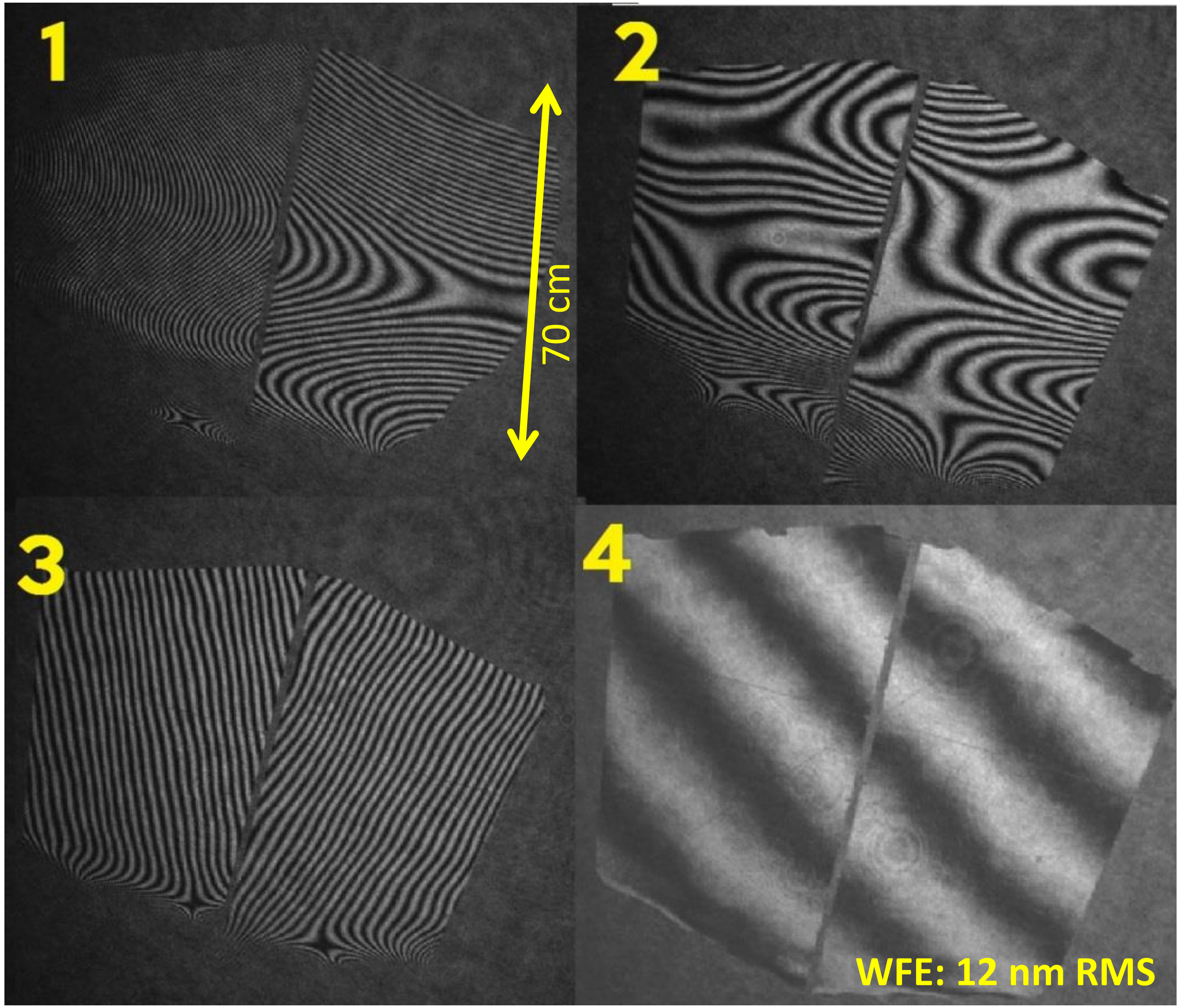
M4DP: optical test result

1: Initial shape

2: 2x10 modes flattening

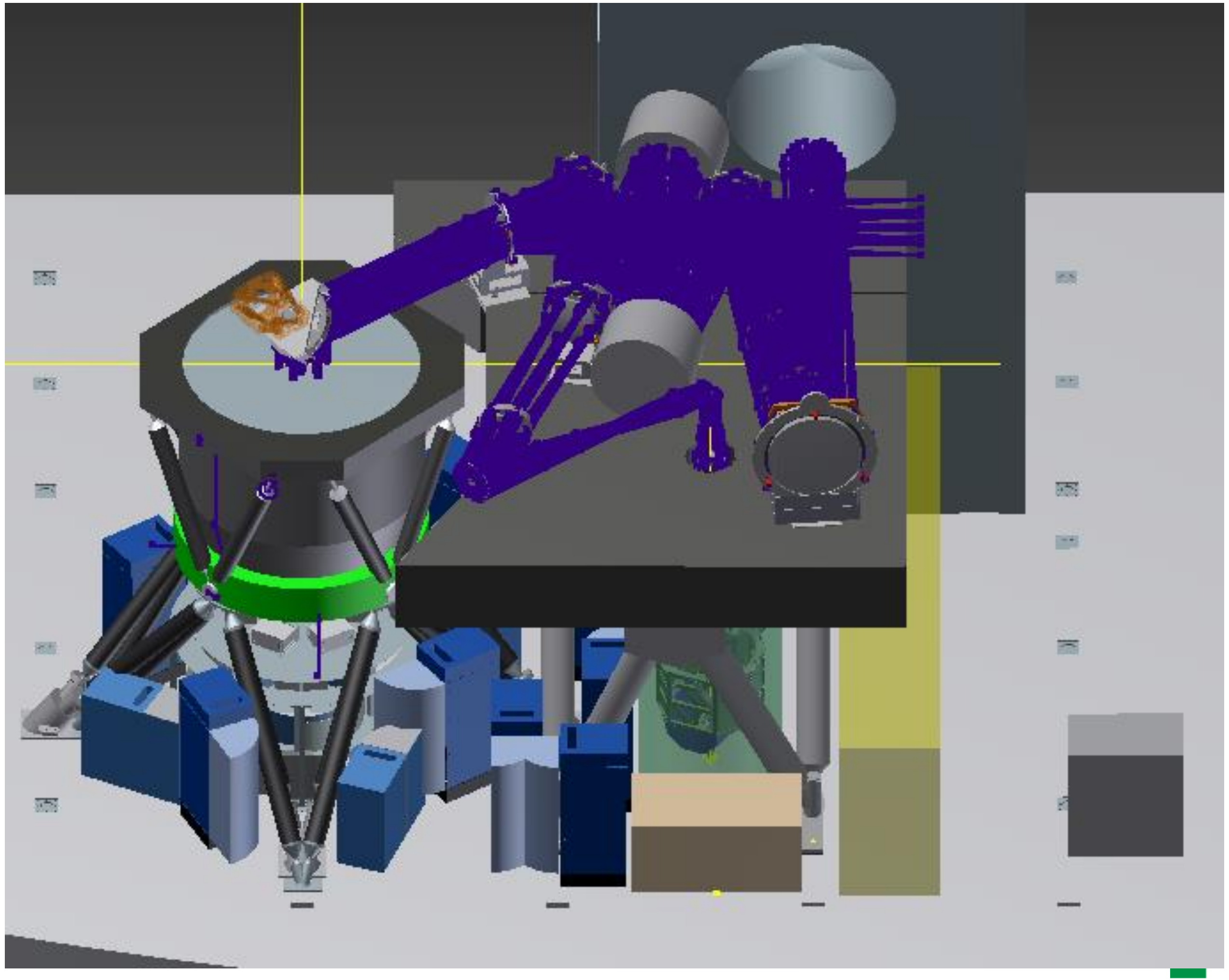
3: high orders flattening, no phasing

4: whole system flattened and co-phased



EELT: MAORY

MAORY: Multi-conjugated Adaptive Optics relaY serving MICADO instrument @EELT first-light



MAORY CONSORTIUM INSTITUTES

INAF

IPAG - Grenoble

MAORY consortium

- INAF (PI: E. Diolaiti)
  - Lead institute (AOBo, IASF-Bo, OAA, OAB, OANa, OAPd)
  - System-level of MAORY
  - Sub-systems: Platform, Post-focal relay optics including deformable mirrors, Real-time computer, NGS wavefront sensor module, Auxiliary equipment, Science support tools
- INSU – IPAG
  - Sub-system: LGS wavefront sensor
- ESO
  - Project customer
  - Supplier of components and services
  - Joint undertakings: adaptive optics wavefront sensor cameras,
    real-time computer

MAORY CONSORTIUM INSTITUTES

INAF

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What will Maory do?

Expected MCAO performance (telescope included)
Assumptions: wavelength 2.2 µm, one deformable mirror in MAORY, 6 LGS, full M1

Strehl ratio	**Sky coverage**	**Conditions**
SR ≈ 0.3 (TBC)	50% (TBC)	Median seeing As close to zenith as possible Field of view 1 arcmin
SR ≈ 0.15 (TBC)	50% (TBC)	Sub-optimal seeing Zenith distance 30° Field of view 2 arcmin
SR ≈ 0.4-0.5 (TBC)	Not applicable	Best seeing Zenith distance 30° Field of view 20 arcsec

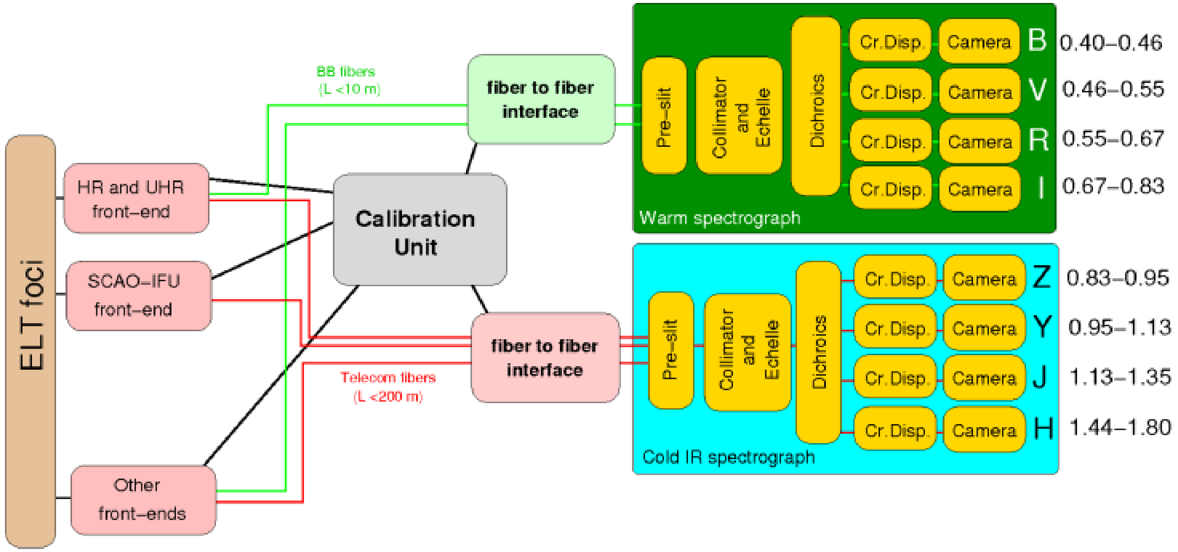
With 2 deformable mirrors in MAORY, performance under median conditions is comparable to performance under best conditions with 1 deformable mirror

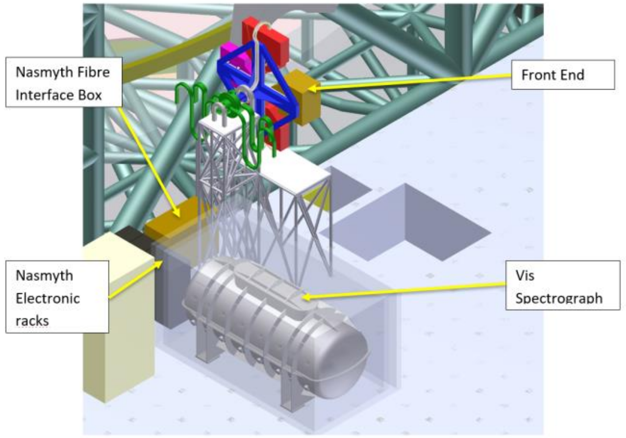
Expected SCAO performance: SR > 0.6 (goal > 0.7)
Conditions: on-axis, zenith angle < 30°, guide star magnitude V < 12, median seeing

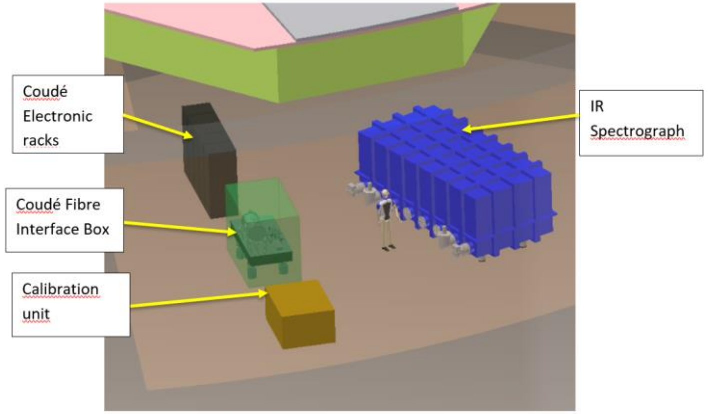
EELT: HIRES

High Resolution 100000 Spectrograph providing from 0,4 to 2,5 um wave coverage

- 2 modules BVRI and ZYJH
- Fiber injection: seeing and diffraciton limited mode

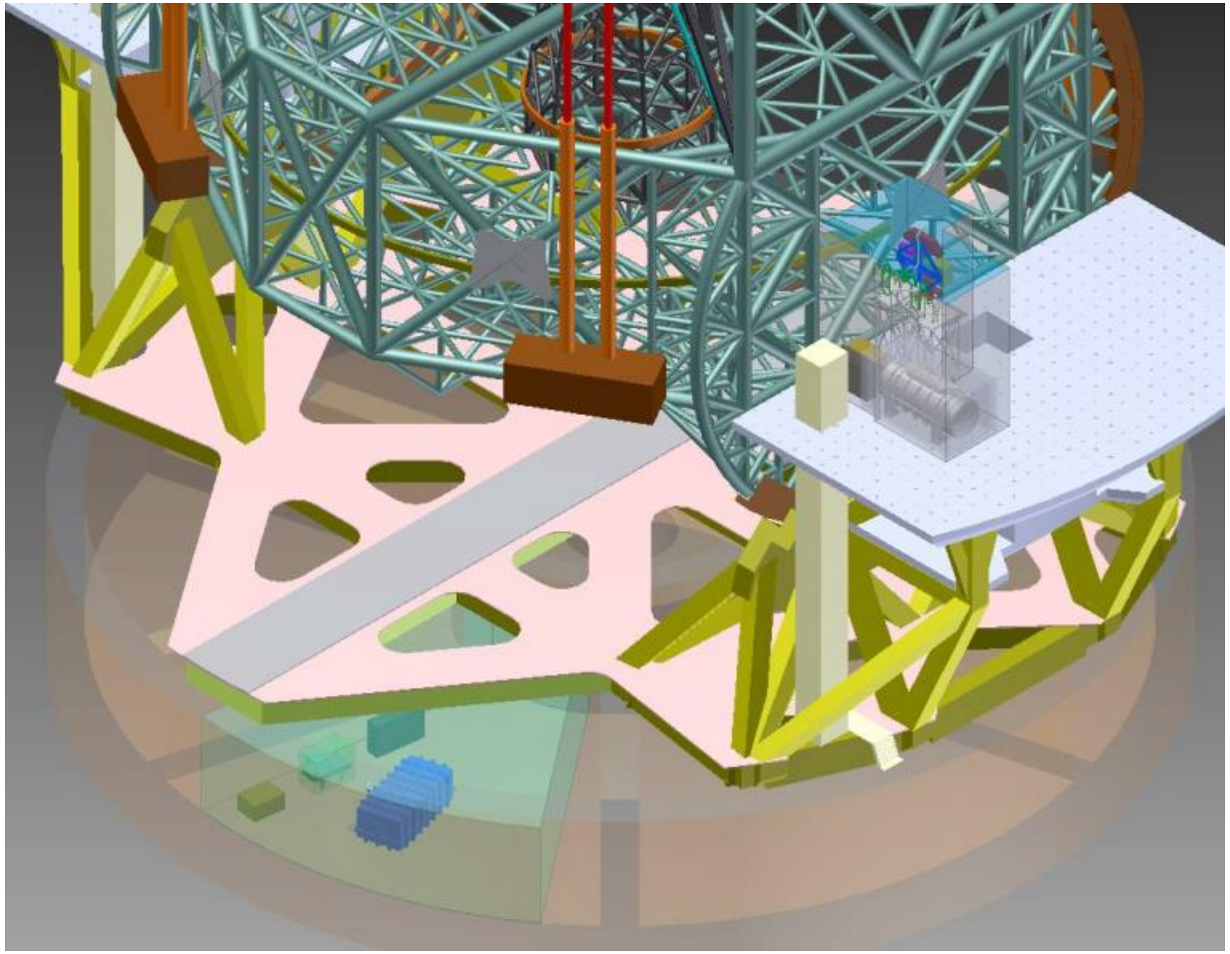






HIRES consortium

- INAF (PI: A.Marconi)
- Consortium Members
  - **Brazil**
  - **Chile**
  - **Denmark**
  - **France**
  - **Germany**
  - **Italy**
  - **Poland**
  - **Portugal**
  - **Spain**
  - **Sweden**
  - **Switzerland**
  - **UK**



Thank you!