HARMONI Instrument Overview and Procurement Plan

Geneva, April 7th, 2022

Presented by D. Le Mignant (deputy PM)

for the HARMONI consortium

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https://harmoni-elt.physics.ox.ac.uk/

HARMONI

HARMONI is an Integral Field Spectrograph

→ spectral information over a 2D field of view

→ high spatial resolution

- Combination of
  - Exquisite spatial resolution
  - Huge collecting area
- D^4 sensitivity gains in near-IR
- “Point-and-shoot” capability
  - No slit losses
  - No slit positioning uncertainty

Why is HARMONI+LTAO so special?

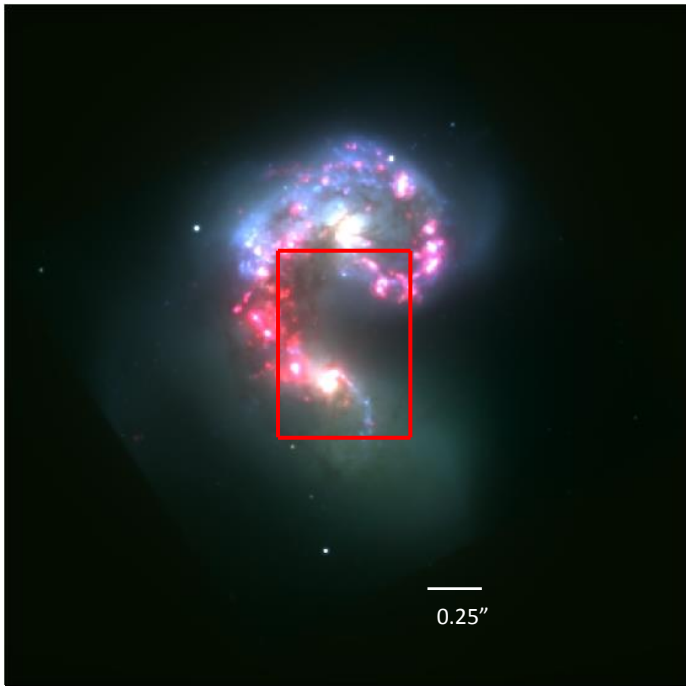
Atmospheric
Seeing Limited
0.65”

VLT SINFONI
AO

20 mas HARMONI
LTAO

10 mas HARMONI
LTAO

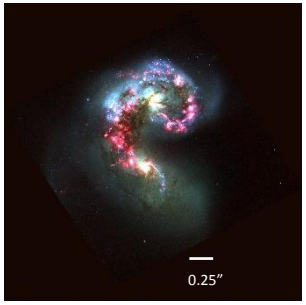
4 mas HARMONI
LTAO



Wavelengths at z=2:

R: 1.974 microns (Hα)
G: 1.650 microns (V band)
B: 1.305 microns (B band)

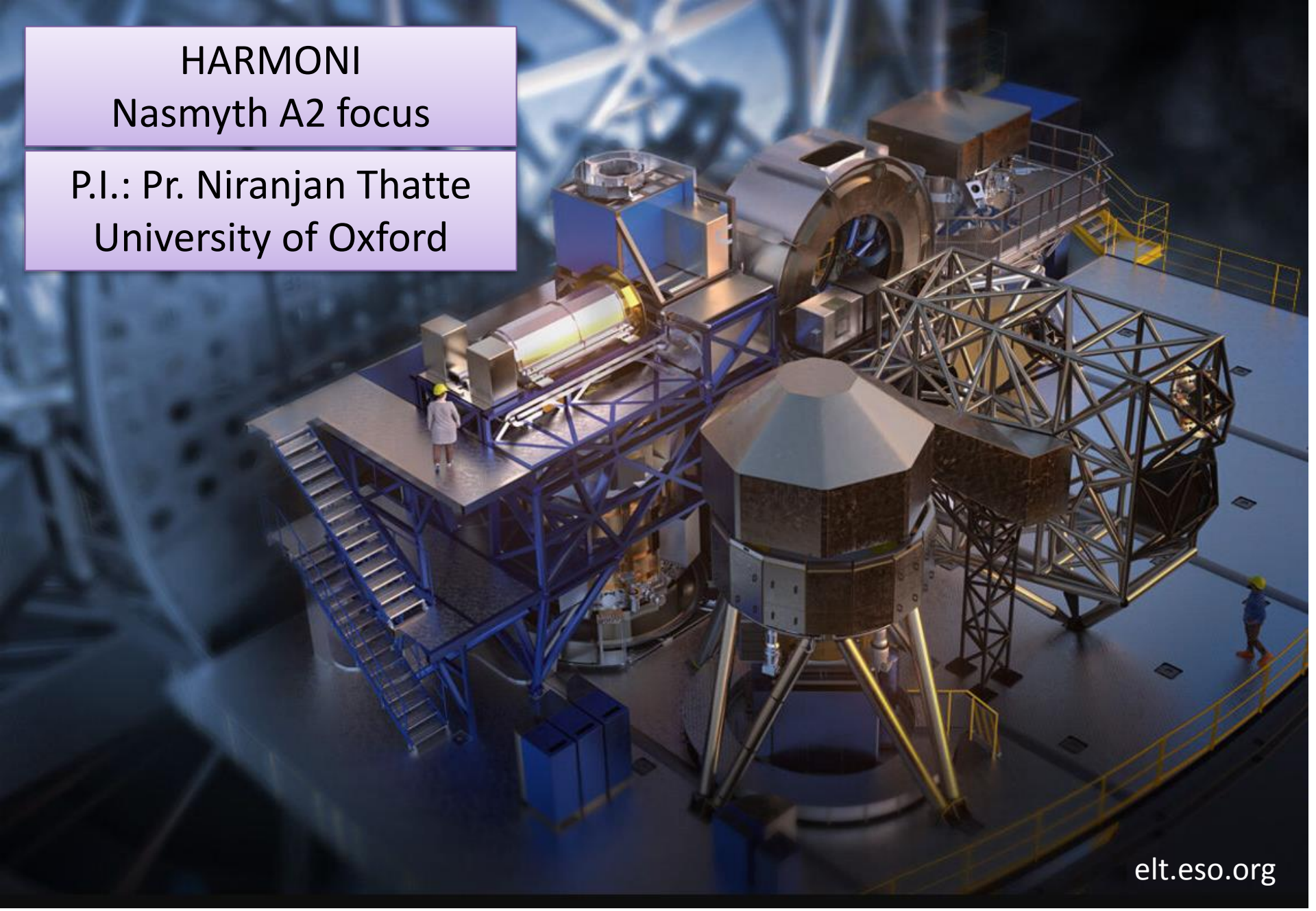
Brackets denote emitted wavelength band



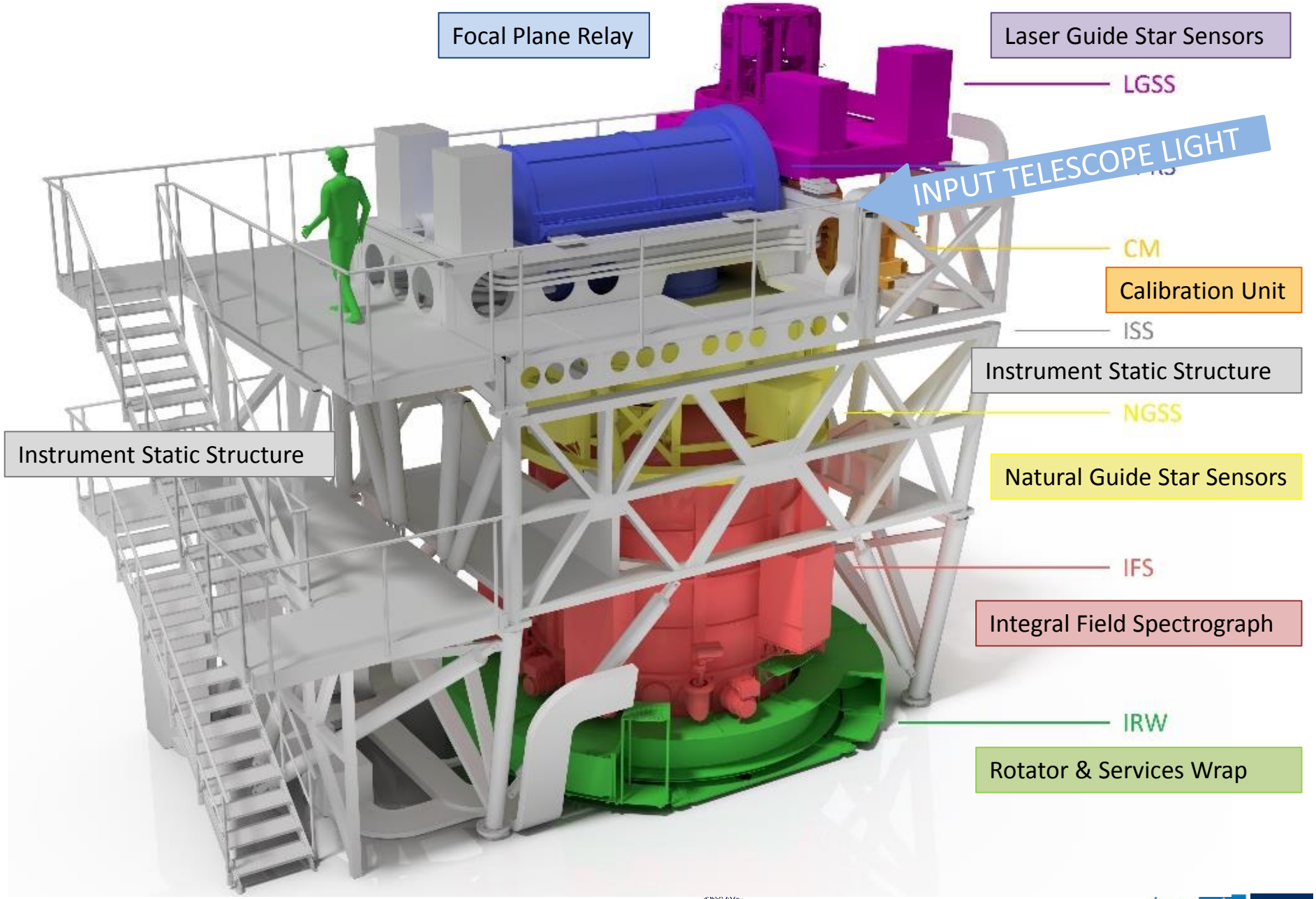
LTAO: Laser Tomography Adaptive Optics

HARMONI
Nasmyth A2 focus

P.I.: Pr. Niranjan Thatte
University of Oxford

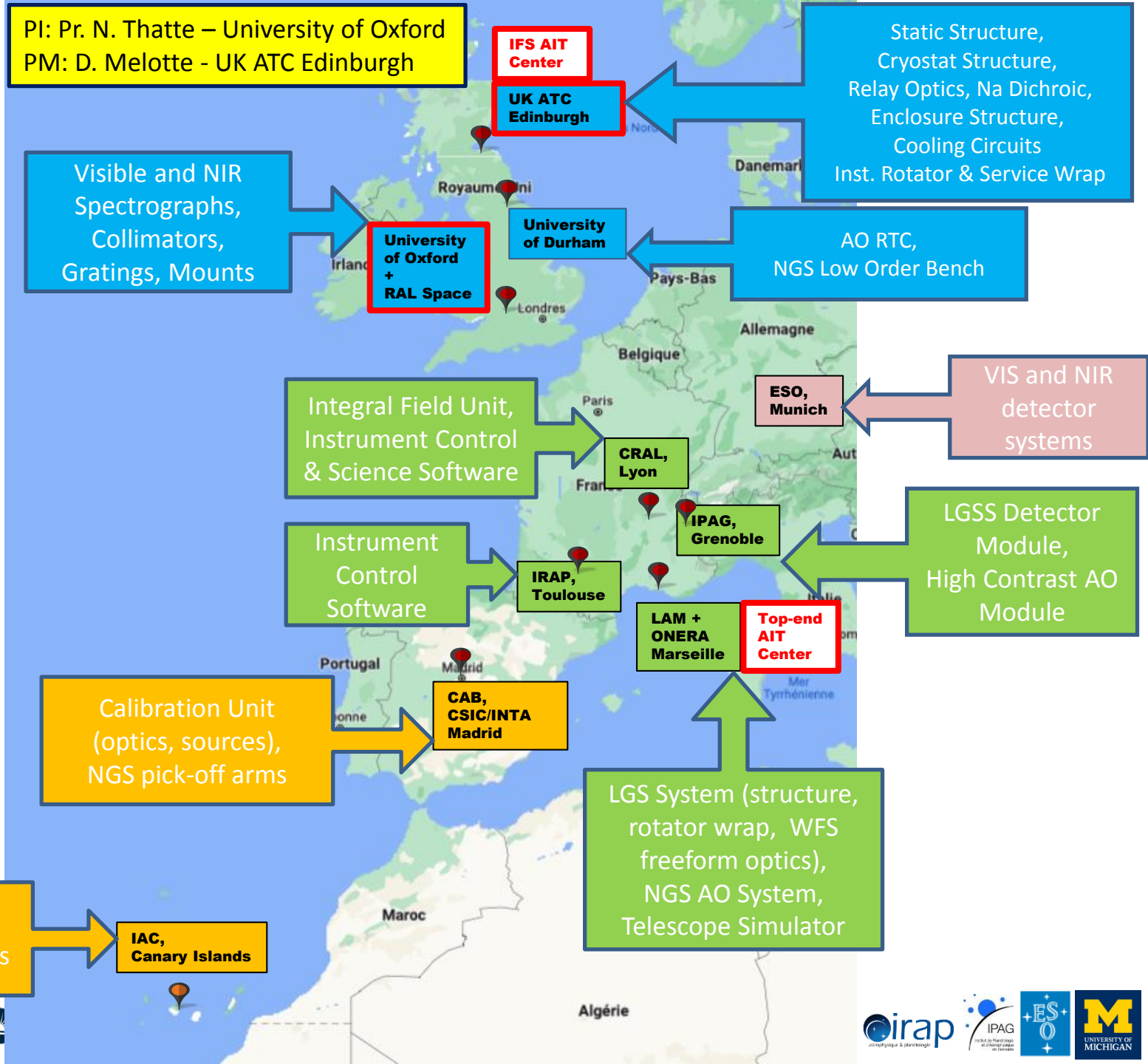


elt.eso.org


Focal Plane Relay
Laser Guide Star Sensors
LGSS
INPUT TELESCOPE LIGHT
CM
Calibration Unit
ISS
Instrument Static Structure
NGSS
Instrument Static Structure
Natural Guide Star Sensors
IFS
Integral Field Spectrograph
IRW
Rotator & Services Wrap

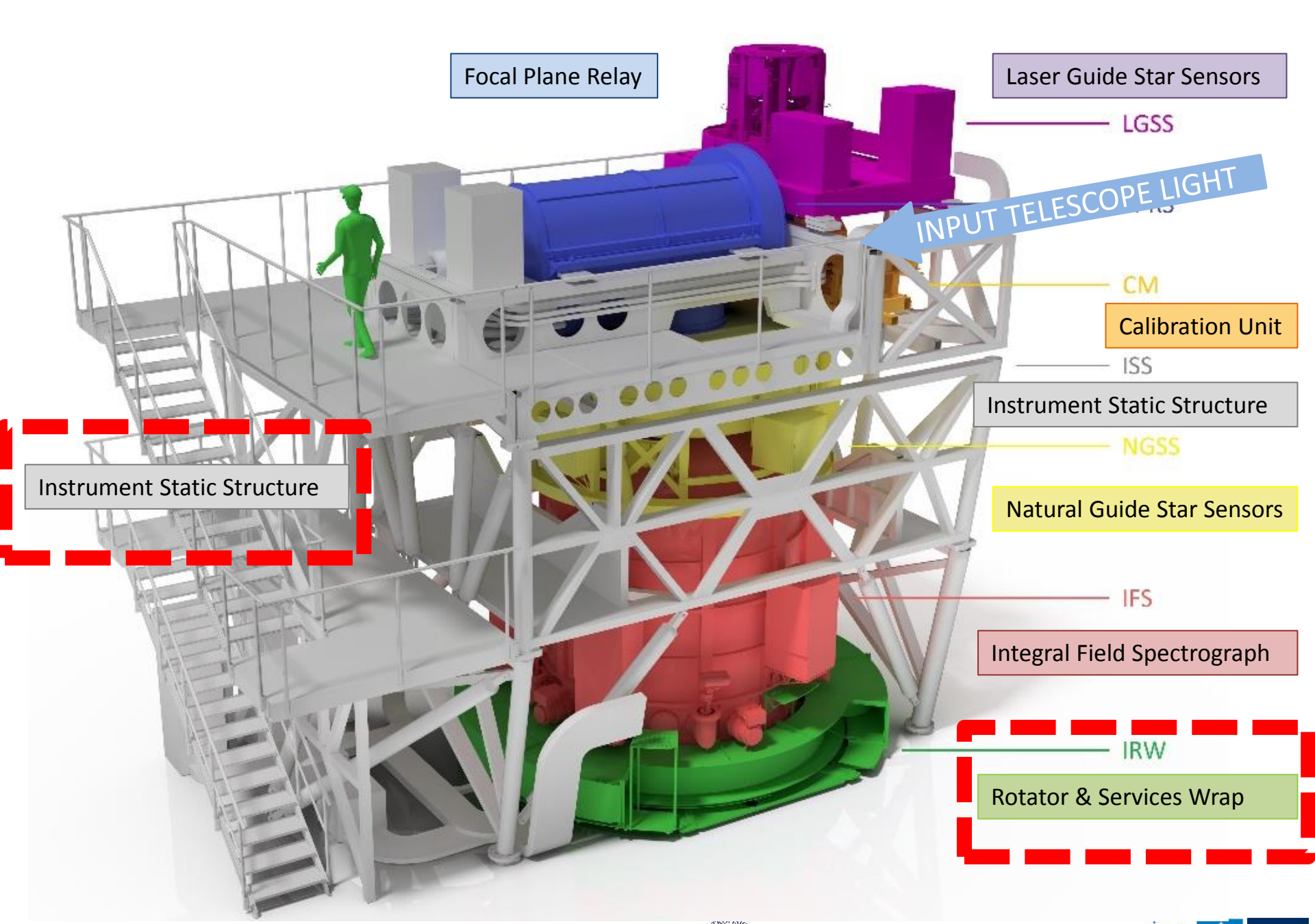
Glossary:
IFU: Integral Field Unit
AO: Adaptive Optics
RTC: Real Time Control
LGS: Laser Guide Star
NGS: Natural Guide Star
WFS: wavefront sensor

PI: Pr. N. Thatte – University of Oxford
PM: D. Melotte - UK ATC Edinburgh



Instrument Development Snapshot

- Final Design Review currently paused, should resume in Sept. 2022.
- In parallel: RFI for spectrograph optics, gratings, mounts, freeform optics launched from various partners
- Integral Field Unit Early Procurement in Sept. 2022
- **Procurement phase starts in mid-2023**
- **MAIT phase till 2026/27 for the sub-systems**
- Instrument acceptance Europe in 2028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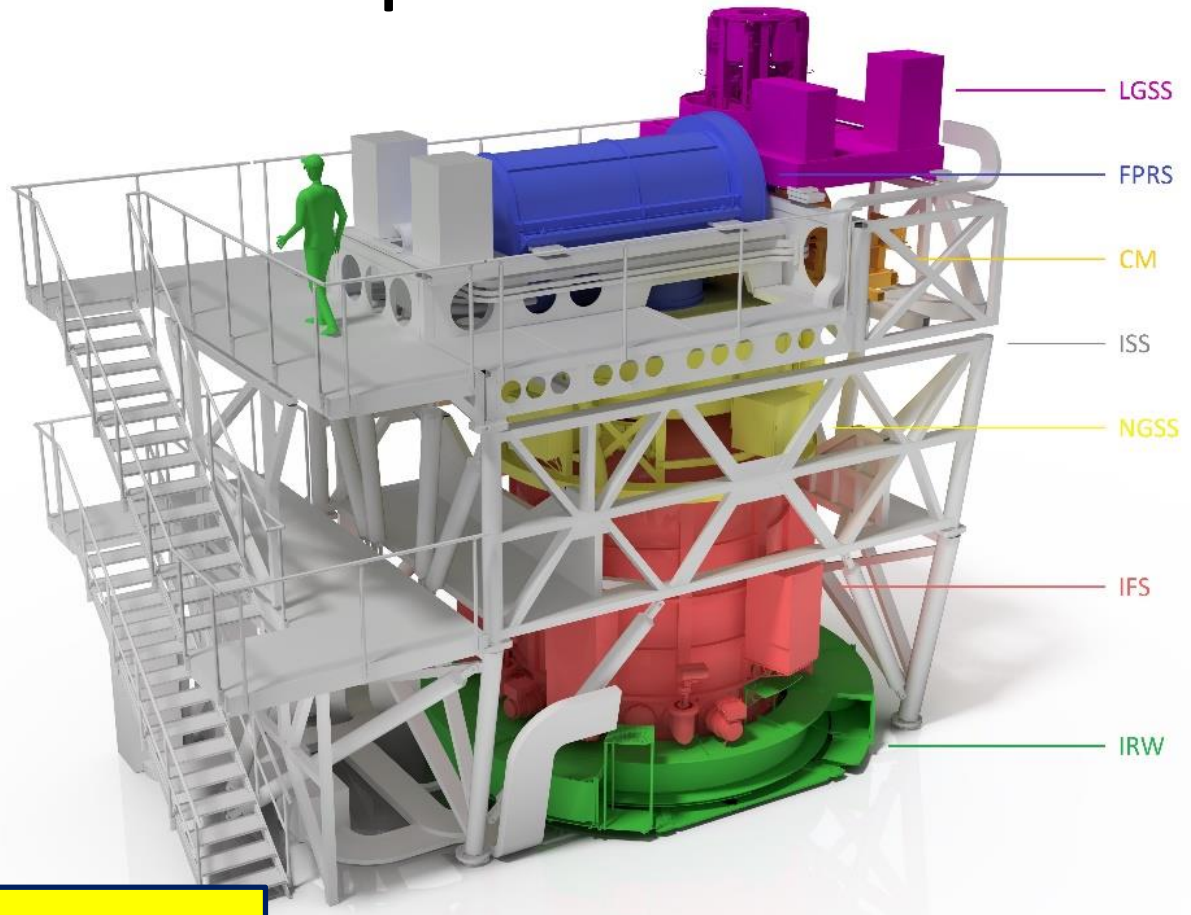
Instrument Structure
Main and top frame

- Mechanical manufacturing
- Aluminium 6082
- 9.3m x 5.6m x 6.7m (LxBxH)



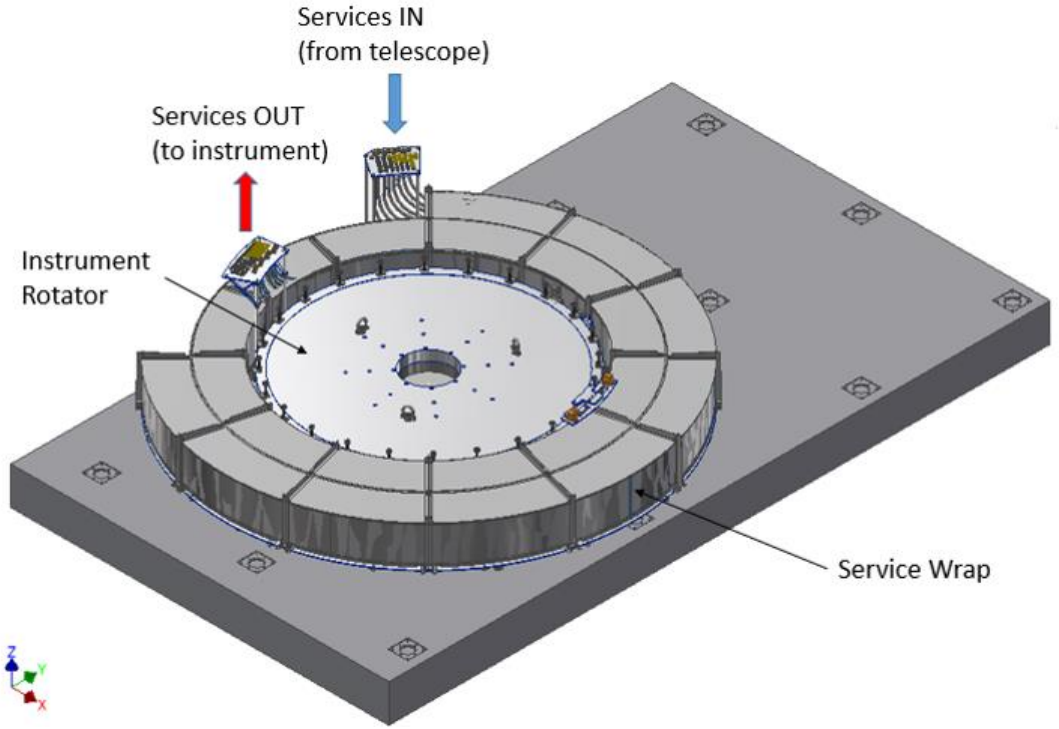
Contact:
UK ATC (Edinburgh)
Mr. William HUMPHREYS – william.humphreys@stfc.ac.uk

Instrument Rotator and Services Wrap

- Developed by UK ATC (Edinburgh)
- Provide structural support for the IFS
- Position the IFS and NGSS
  - Angular acceleration range of -1 arcsecond/s² to +1 arcsecond/s².
  - Rotational velocities up to 8 °/s.

- Cable wrap delivers services (power, signals, He, coolant etc.) from the static platform to the rotating systems of the instrument

- Considering both buying the parts and doing the AIT in house OR buying in the whole system



Mass limit 10,000 kg
Rotator Diameter: 3.75m
Cable Wrap Diameter: 5.5m

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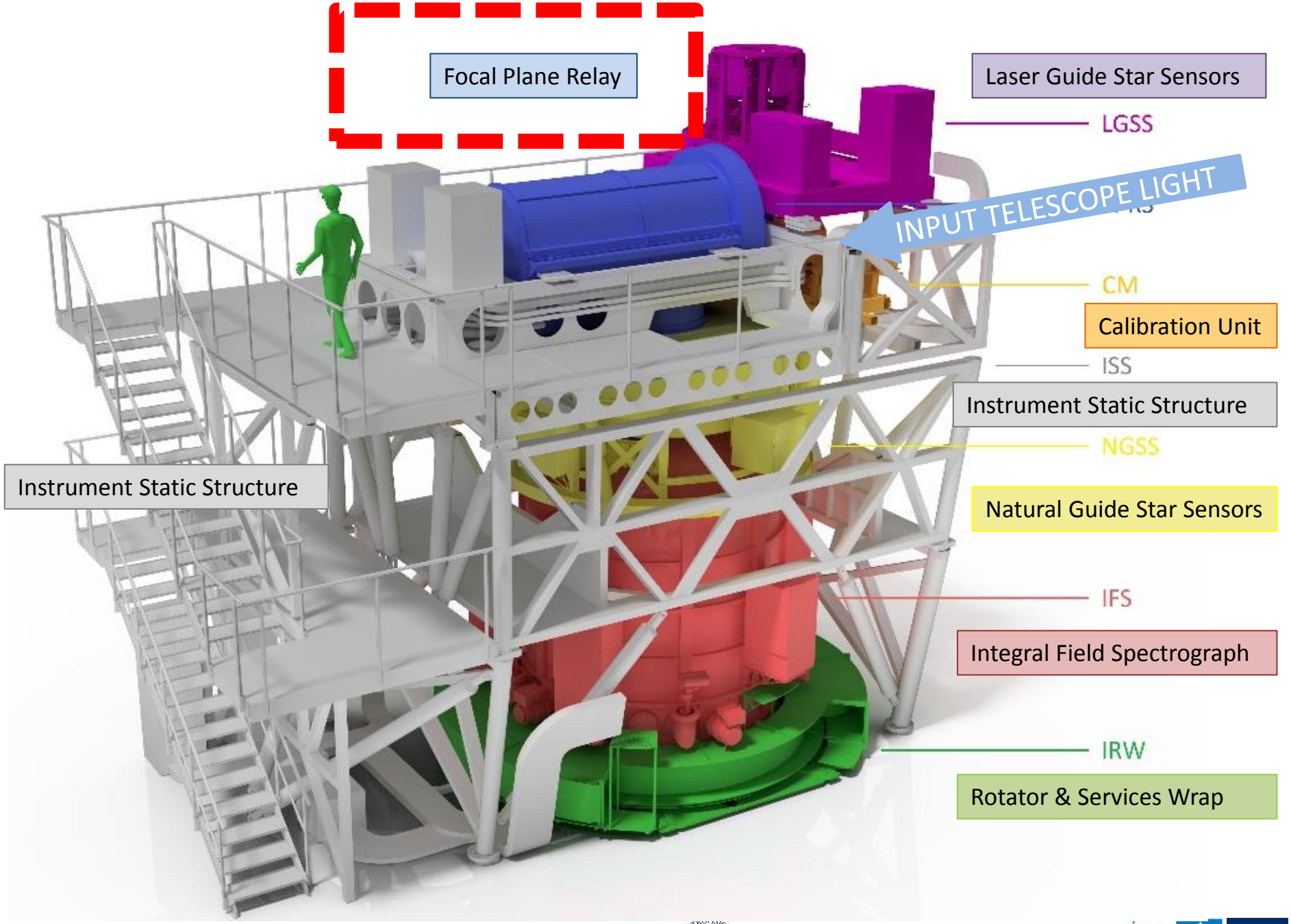
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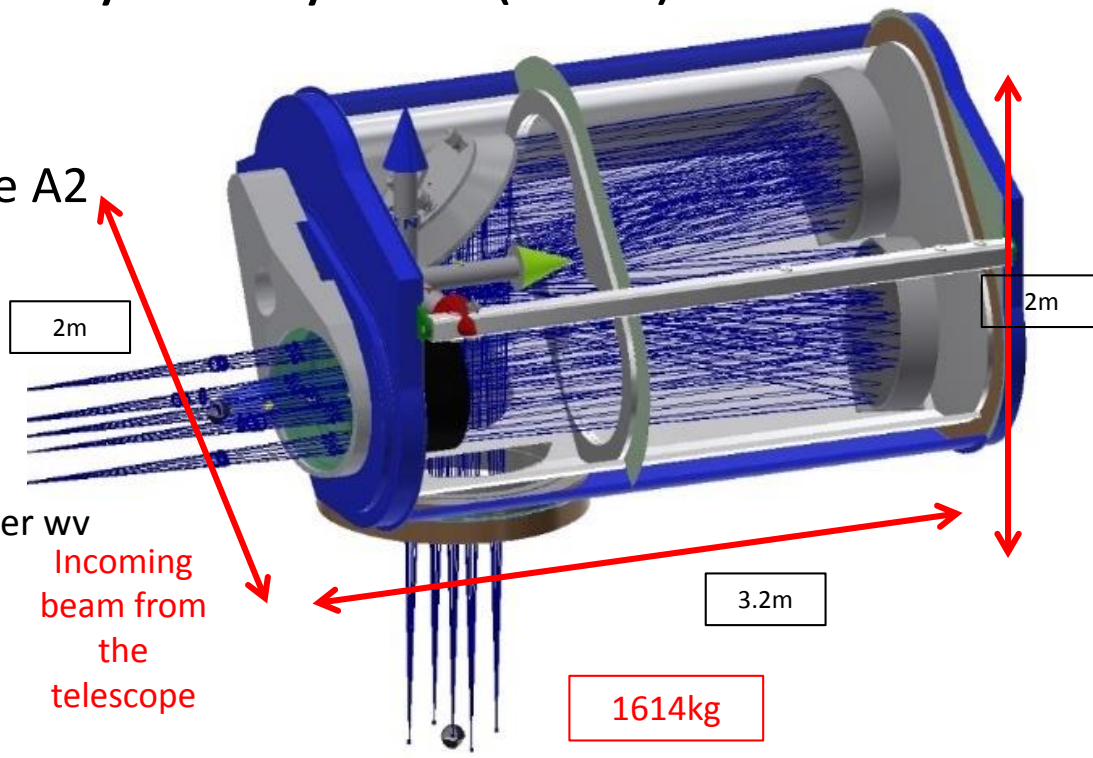
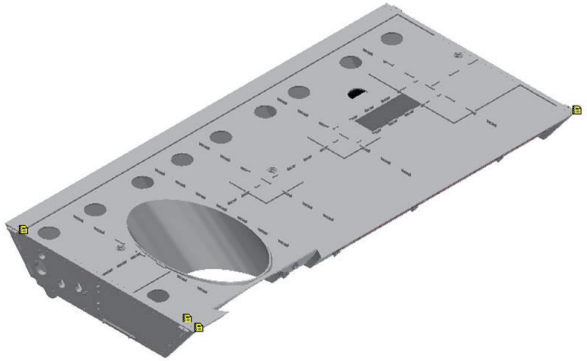
Focal Plane Relay Sub-system (FPRS)

- Developed by UKATC
- Focal Plane Relay relays telescope A2 focus to NGSS/IFS focal plane



- Dichroic optics
  - 620mm clear aperture
  - Reflects Na 589nm and transmitts longer wv
- Relay optics
  - Offner relay passing 2-arcmin (400mm diameter field)

- Optical bench
  - Aluminum bench (2090 x 1290 x 285 mm - ~260 kg



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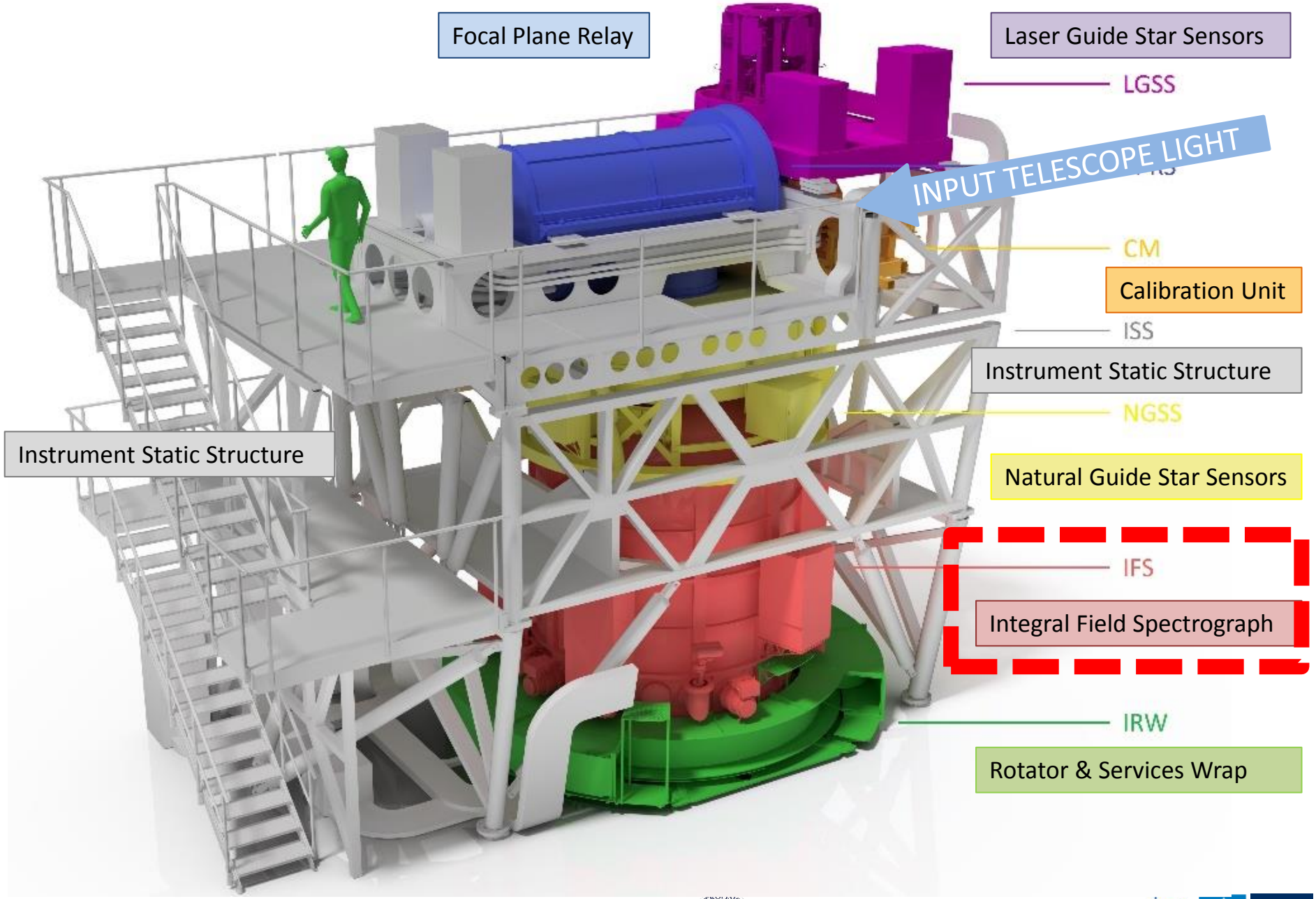
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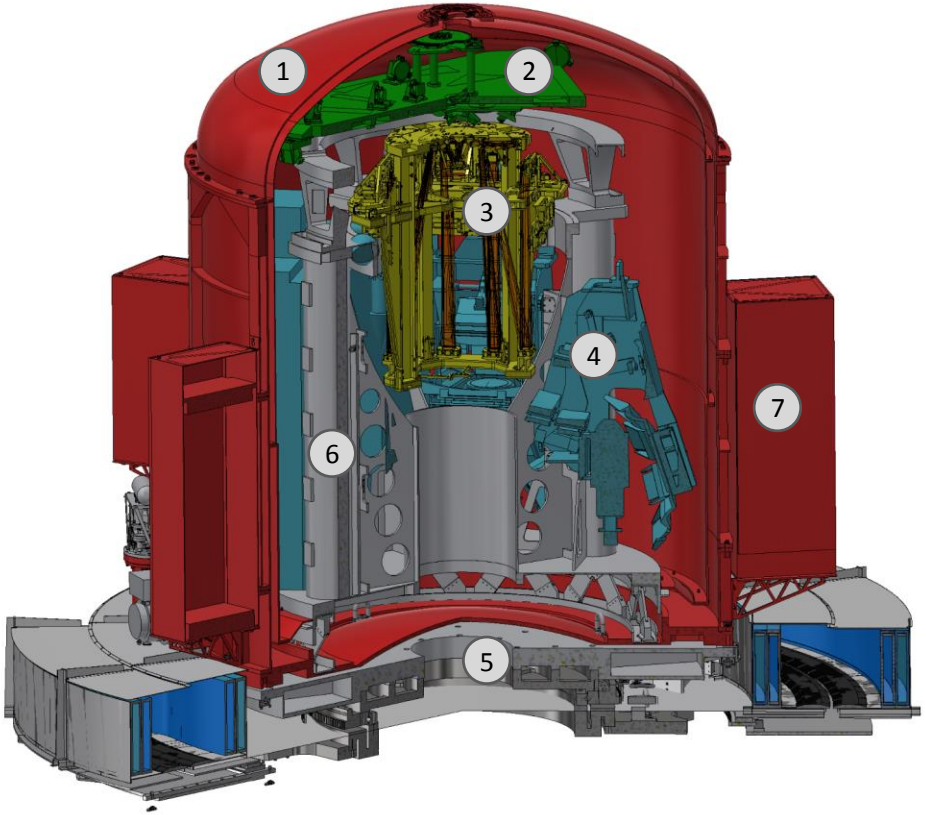
Integral Field Spectrograph

- Takes AO corrected focal plane to integral field spectra
- Mounted in 3.2 m diameter cryostat



Integral Field Spectrograph (IFS)

1. ICR
2. IFS Pre-Optics (IPO)
3. IFS Integral Field Spectrograph (IFU)
4. IFS Spectrograph (ISP)
5. IFS Rotator and Wrap (IRW)
6. ICR Cold Stucture
7. IFS Rotating Electronics Cabinets

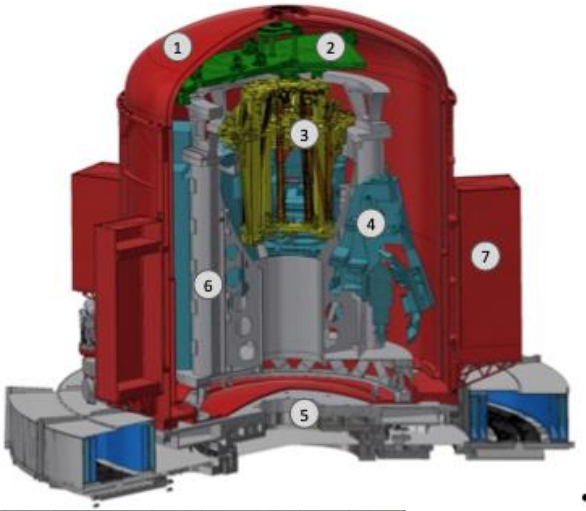
Infrared Science Detector Module (ISDM) (not shown)

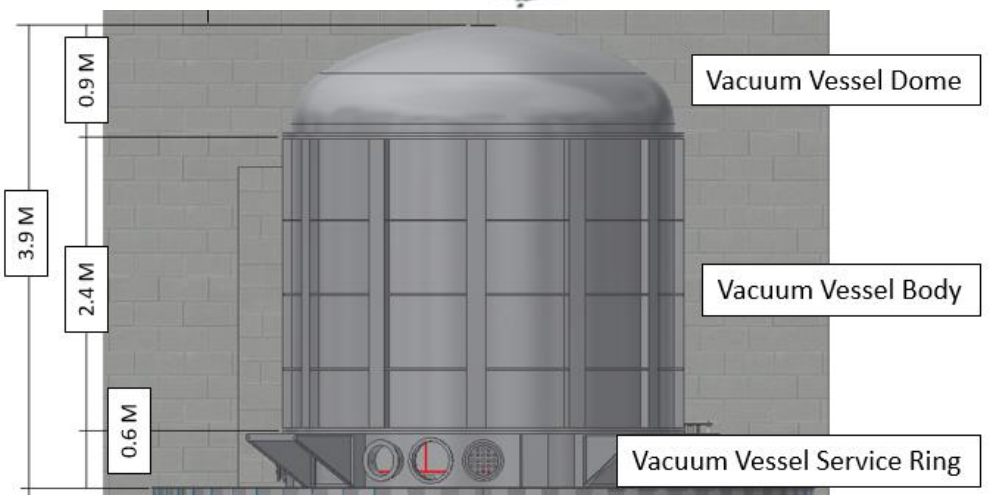
Visible Science Detector Module (ISDM) (not shown)

- Internals at ~130K
  - Pre-optics
  - IFU
  - Spectrographs

IFS Cryostat

- Aluminium pressure vessel to hold a high vacuum operating environment
  - Diameter - 3.75m
  - Mass - 8000kg
- Vacuum system
  - Turbo x3, Roughing x3, Leybold valves
- Cooling circuits
  - LN2 lines
  - Plumbing based on ESO standards





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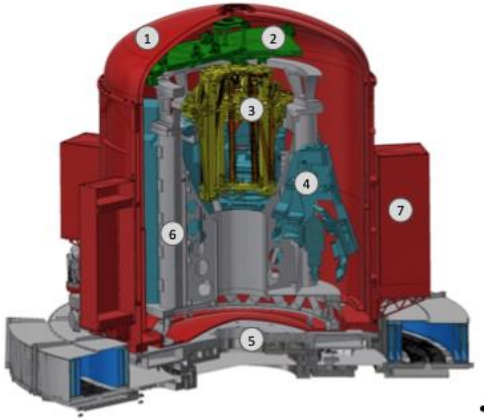
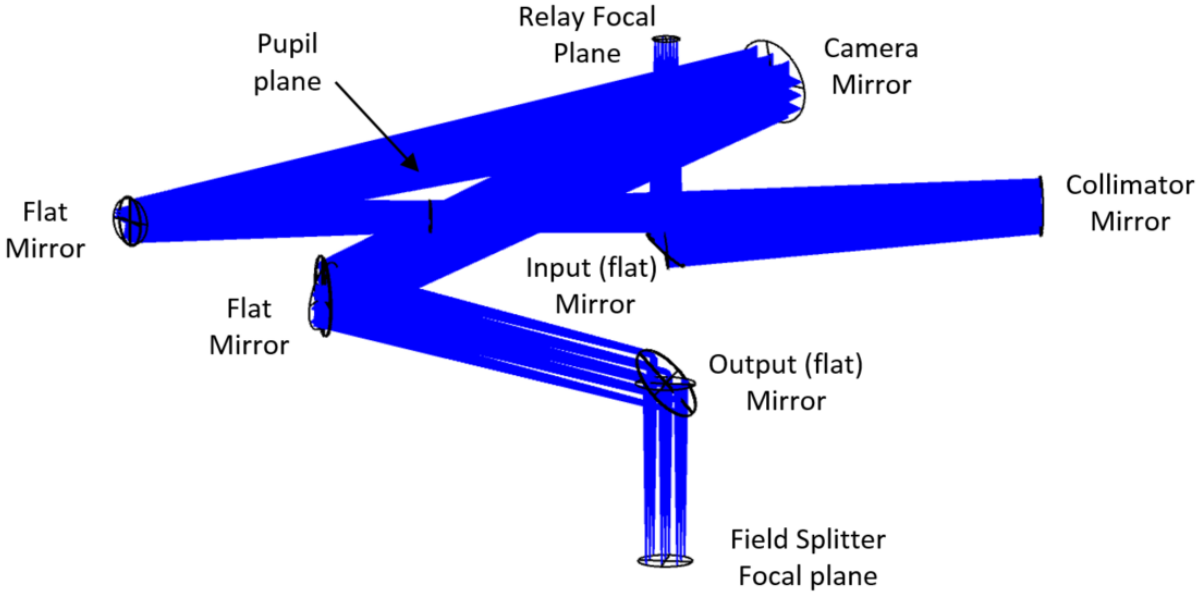
IFS Pre-Optics



- Takes light from corrected focal plane and magnifies for IFU
- Includes field and pupil masks to minimise background
- Includes fast shutter to control exposure times
- Includes filters to block 2nd order light for spectrograph
- Includes four science spatial scales + pupil imaging for alignment

- Toroidal mirrors
- Flat and power mirrors
- Filters and optical coatin

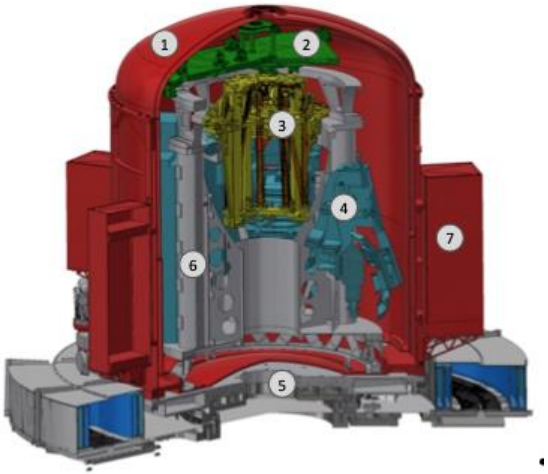


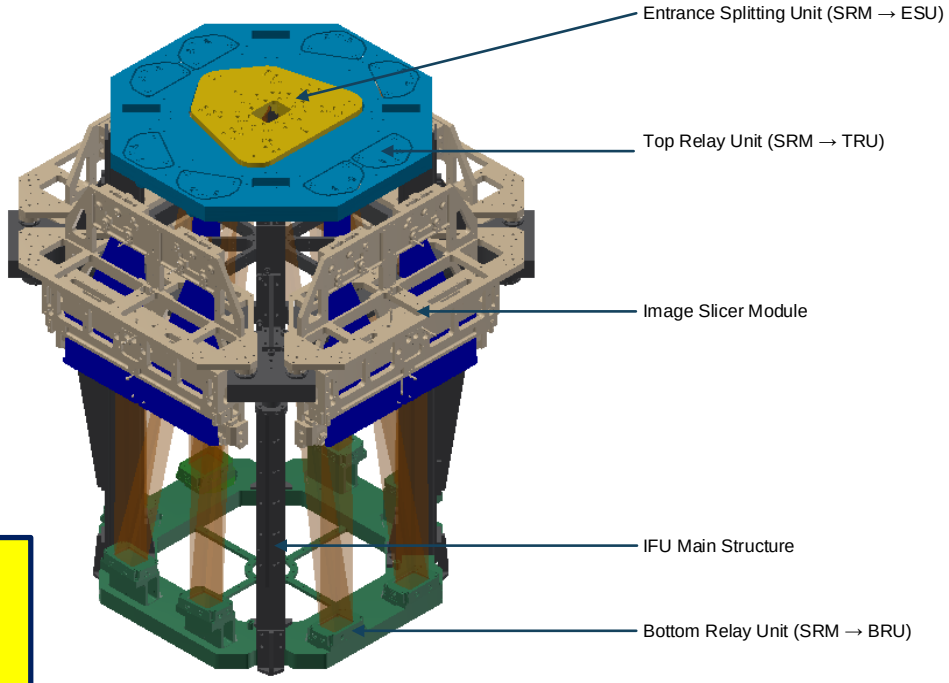
Contact:
IAC (Canary Islands)
Mr. Angel Alonso – aas@iac.es

IFS integral field unit

- Splits single field into four spectrograph entrance slits

- Image slicer module contains 956 individual mirrors!
- Using MUSE heritage for technology and development

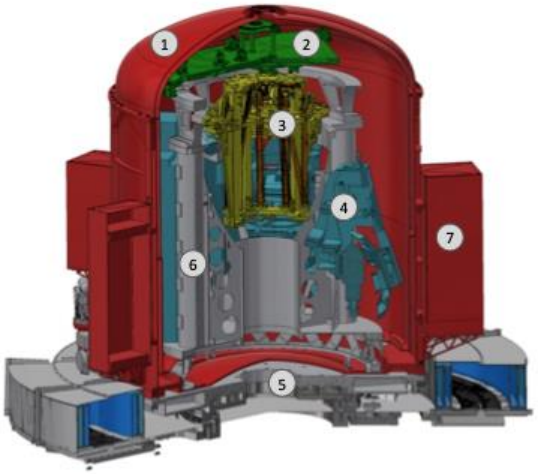




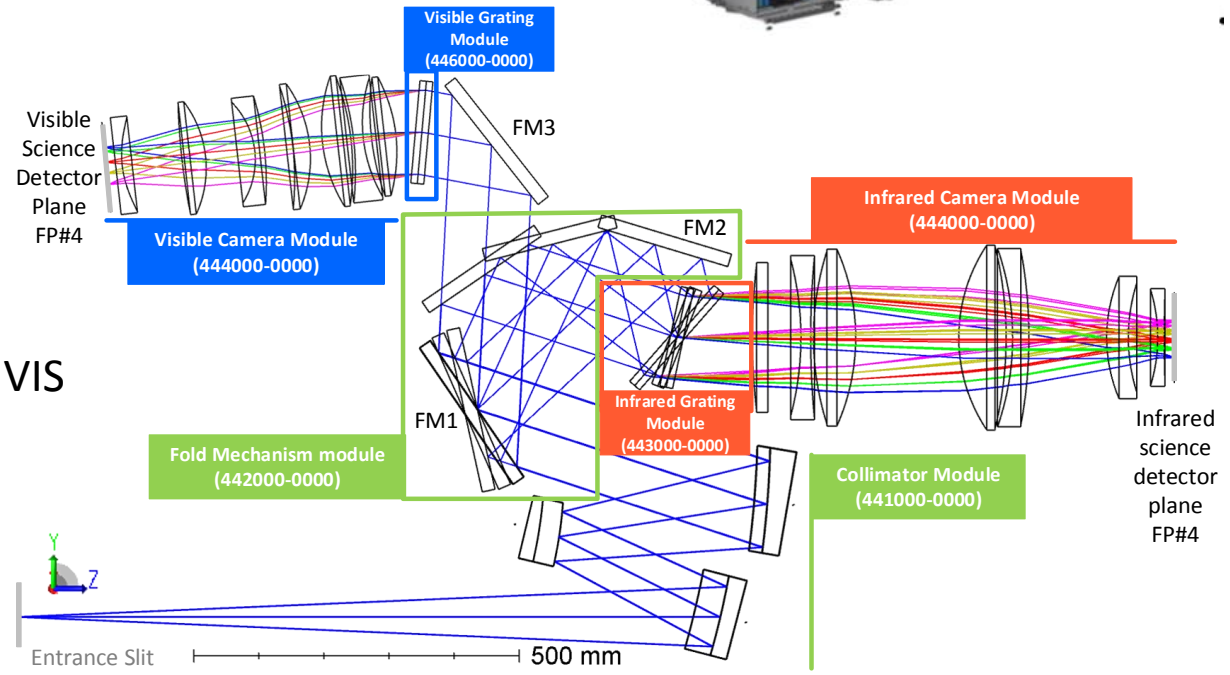
Contact:
CRAL – Lyon , France
Mr. Alban REMILLIEUX – alban.remillieux@univ-lyon1.fr

IFS Spectrograph

- 4 IR and 2 VIS spectrographs channels are developed by University of Oxford & RAL Space
- Reflective collimator + refractive cameras



- 10 NIR VPH gratings
- Feeds 8k x 4k focal planes
- 4 copies – only 2 fitted with VIS cameras



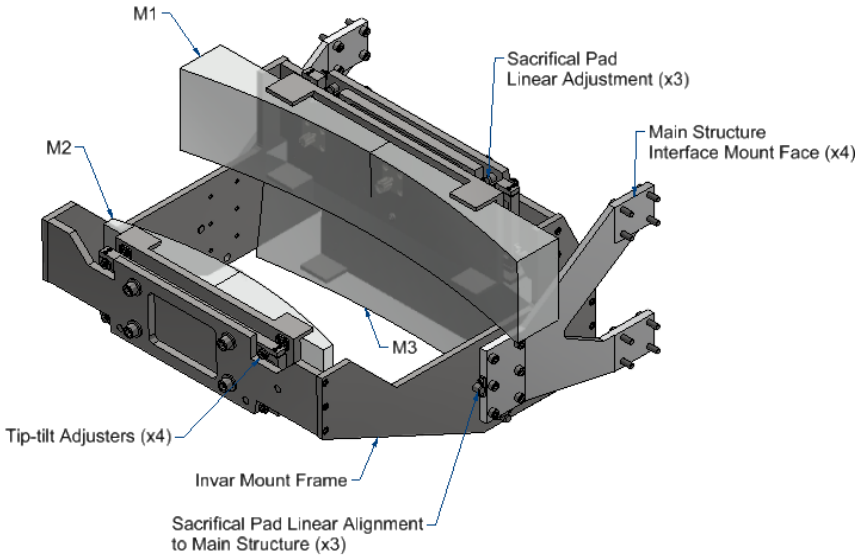
Contact:
University of Oxford
Ms. Zeynep Ozer – zeynep.ozer@physics.ox.ac.uk

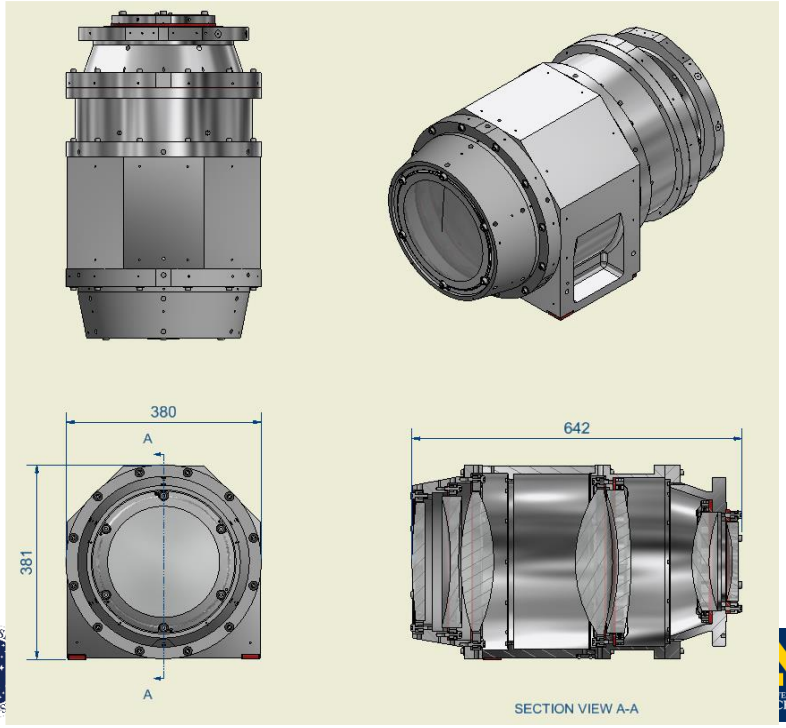
Detectors, controllers and mounts are developed by ESO - Garching

ISP Collimators & Cameras

#	Description	Quantity
1	Collimator Mirrors	Total: 12 ea. 3 ea. mirrors in 4 spectrographs
2	IR Camera Lenses	Total: 28 ea. 7 ea. lenses in 4 spectrographs
3	VIS Camera Lenses	Total: 14 ea. 7 ea. lenses in 2 spectrographs

T=130K

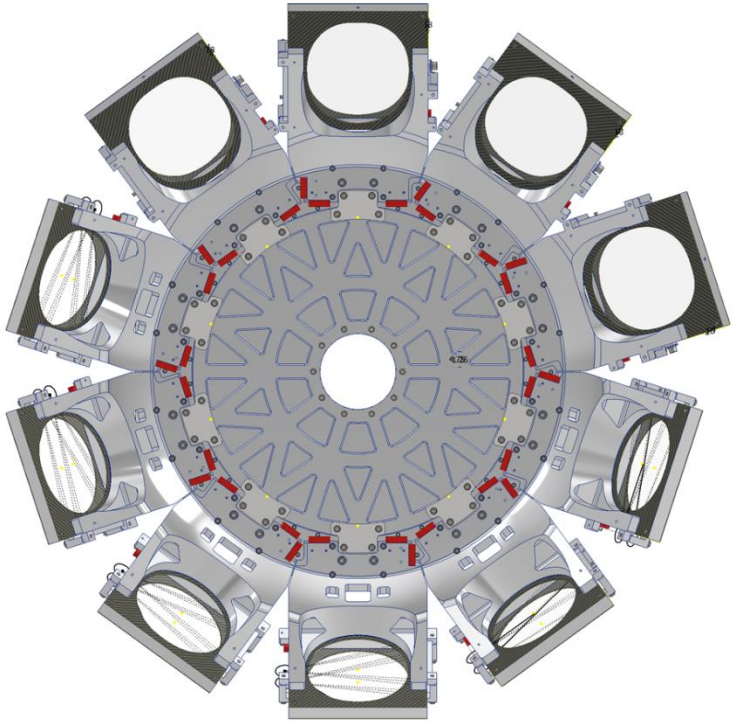




Contact:
University of Oxford
Ms. Zeynep Ozer – zeynep.ozer@physics.ox.ac.uk

ISP Gratings, Wheel and Mounts

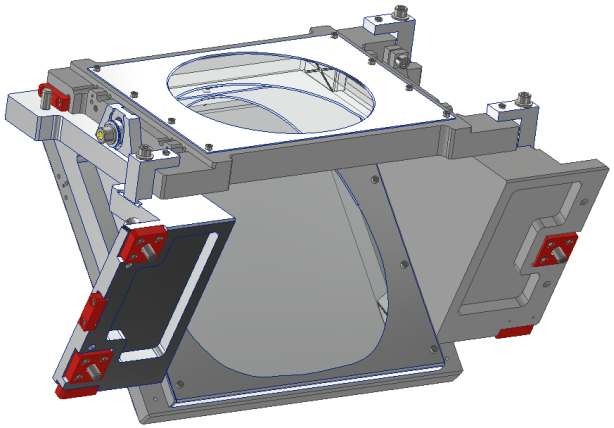
IR grating wheel
clear aperture ~150 mm



4	IR Gratings + VIS Gratings	Total: 42 ea. 10 ea. IR gratings in 4 spectrographs 1 ea. VIS grating in 2 spectrographs

T=130K

VIS grating module
Clear aperture ~150mm



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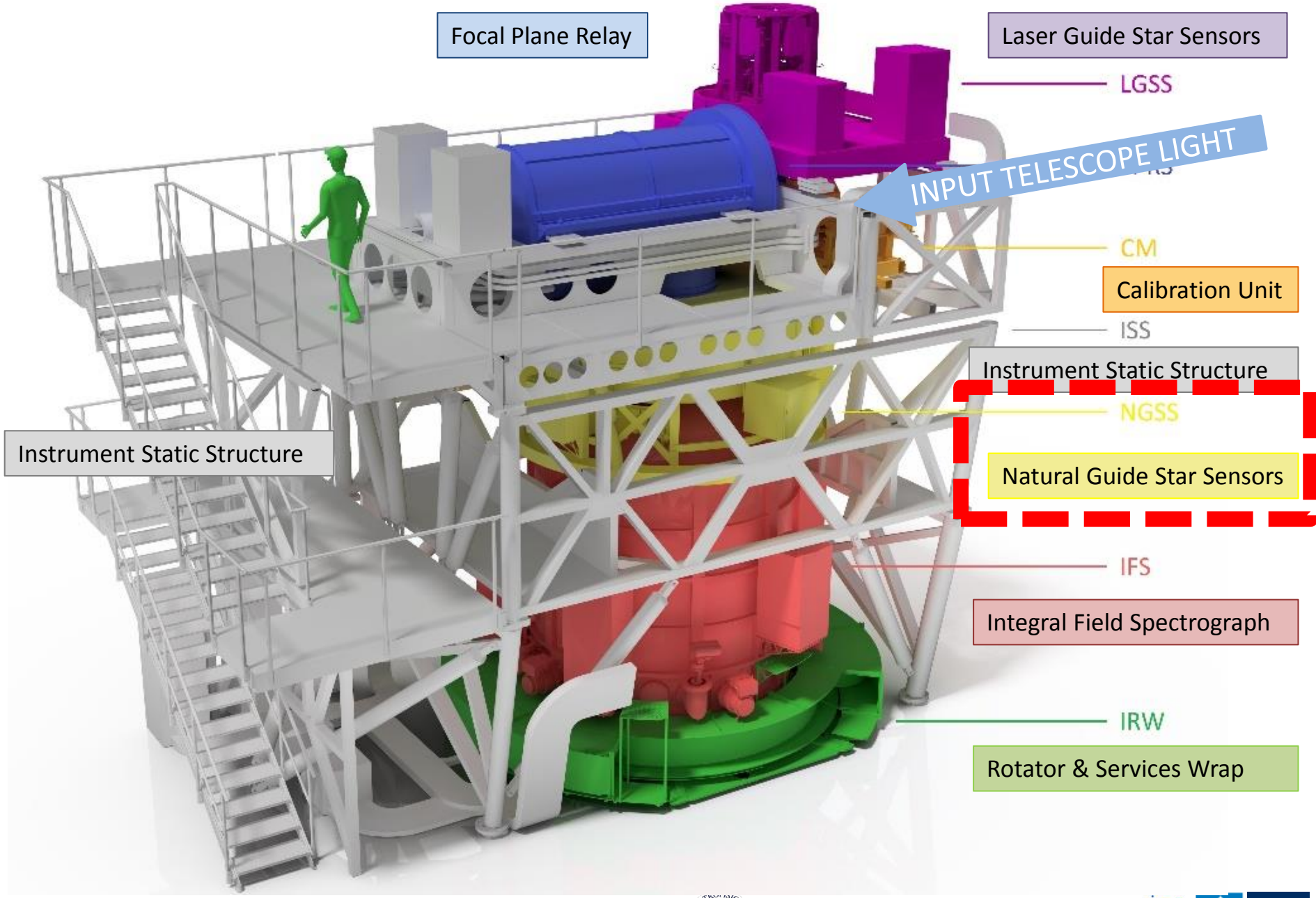
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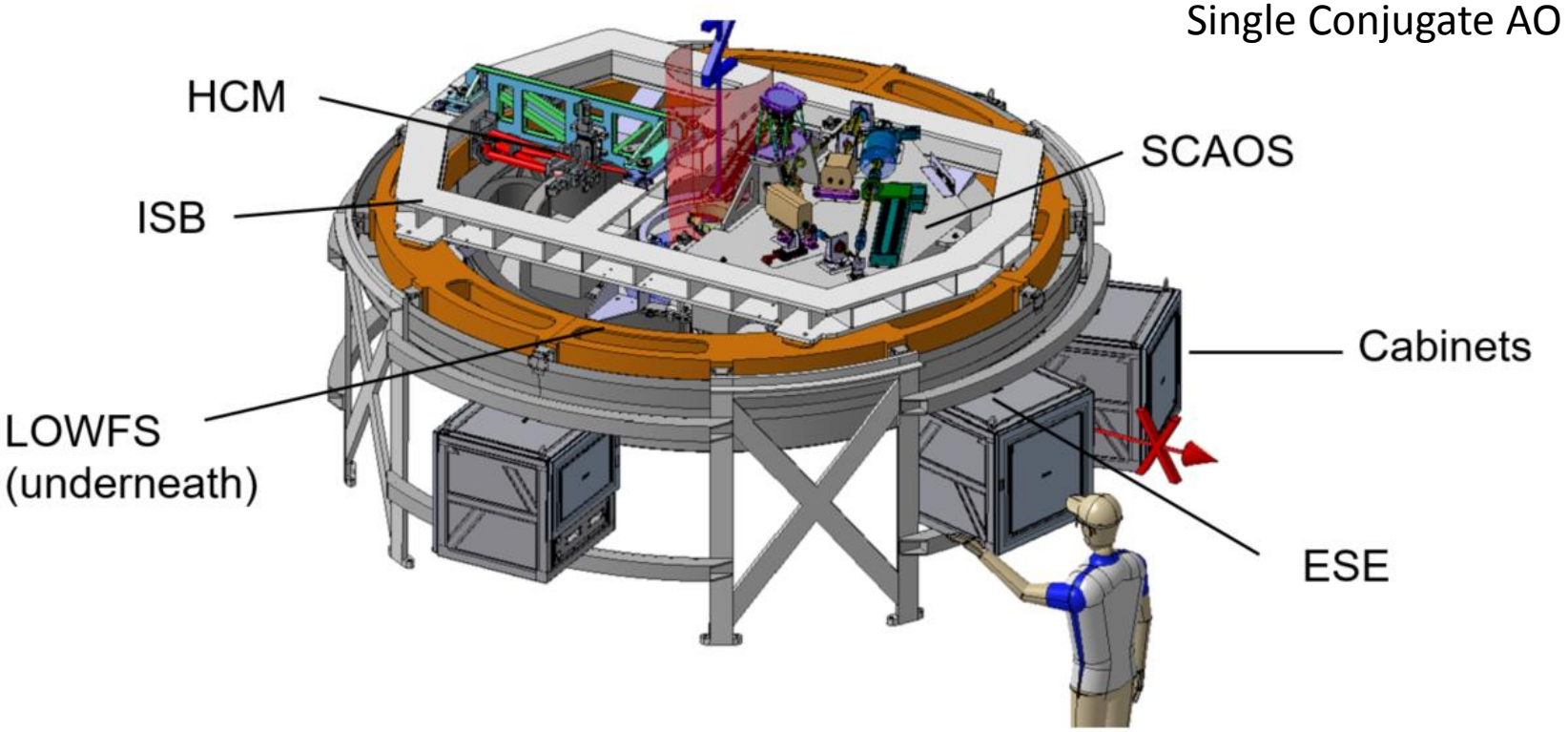
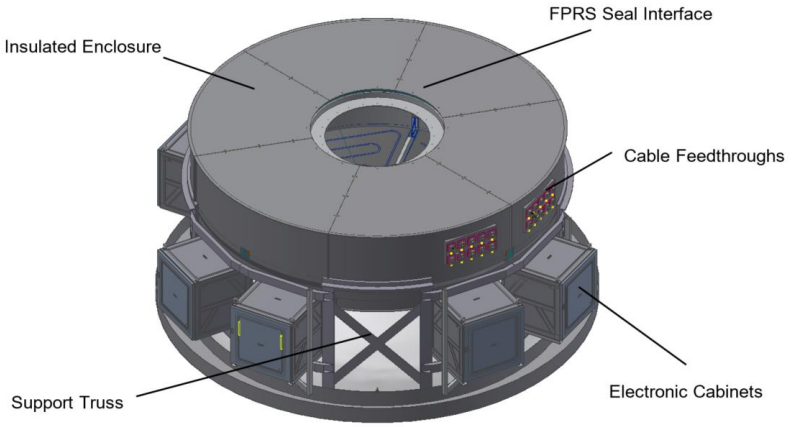
High Contrast Module

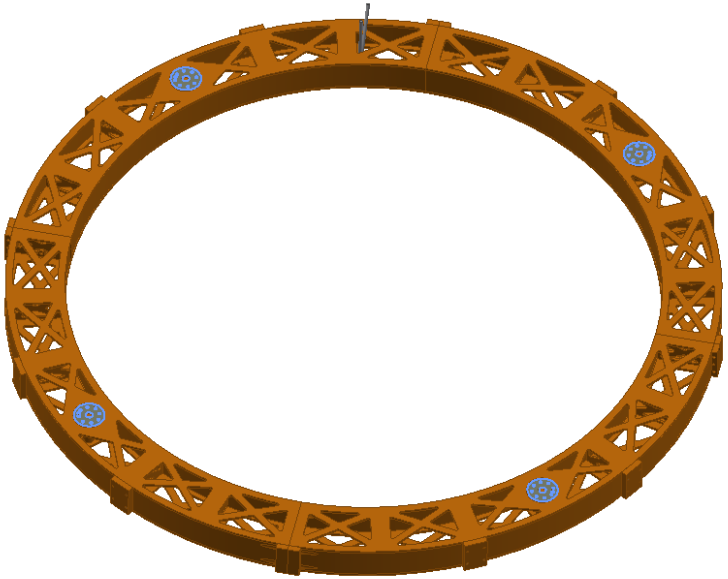
Single Conjugate AO



NGSS Enclosure

- Developed by UKATC
- An aluminium enclosure, which maintains the internal temperature at a constant +2°C to reduce thermal background from the optics.
- Outer Diameter - 3.75m





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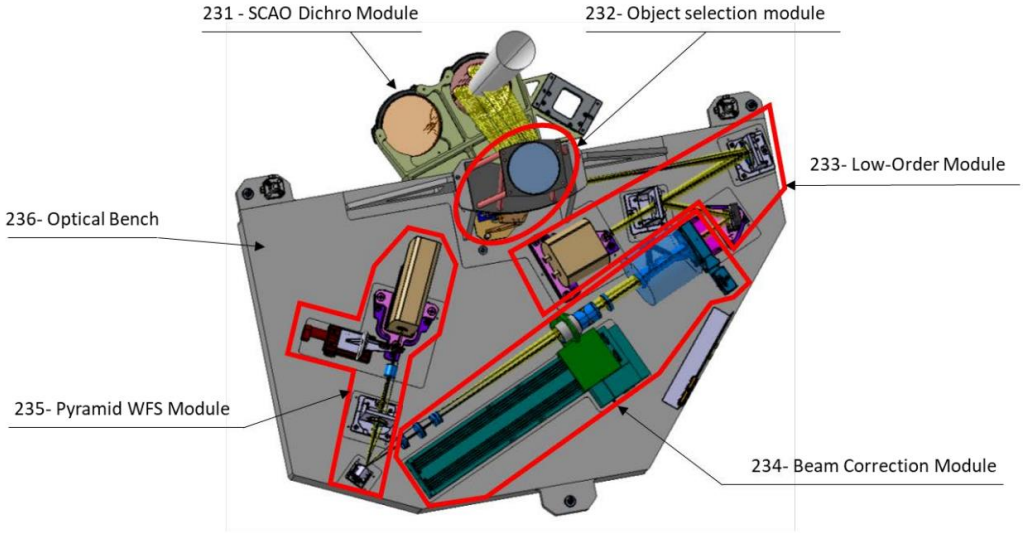
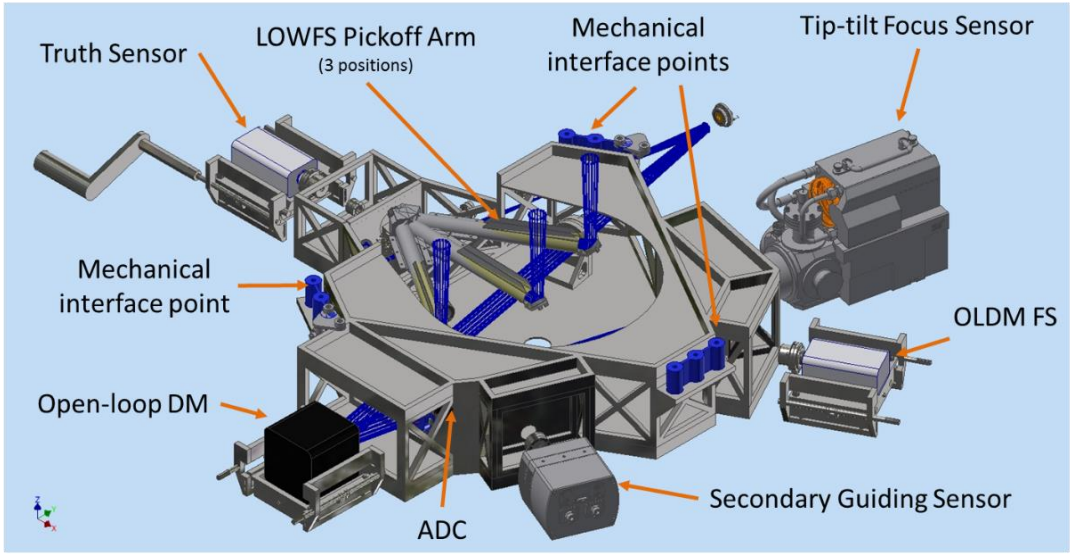
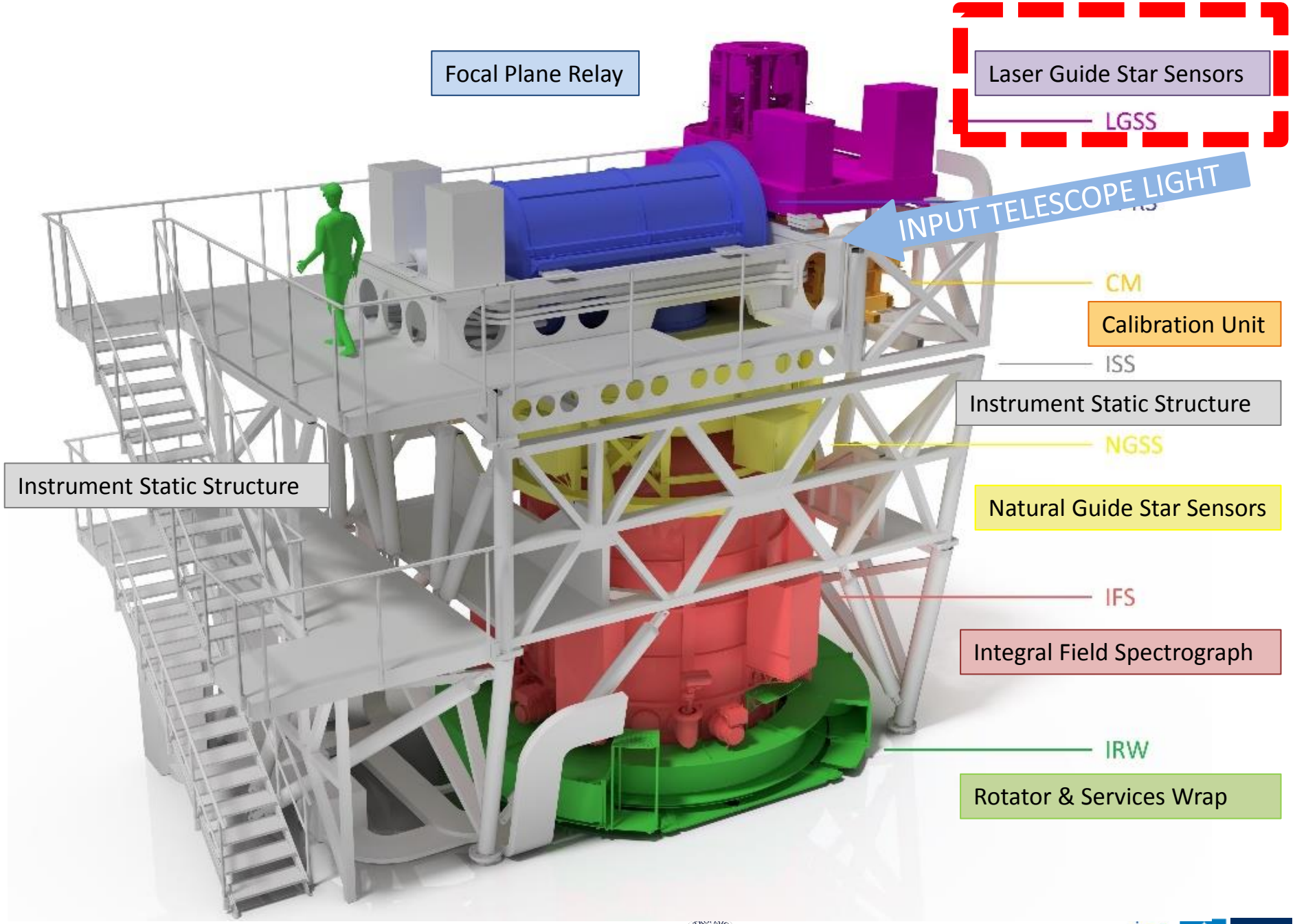
NGSS

- Contains natural guide star sensors
  - SCAO
  - HCM
  - LOWFS



- Deformable mirrors defined
- Pyramid WFS for SCAO
- Many small optical surfaces

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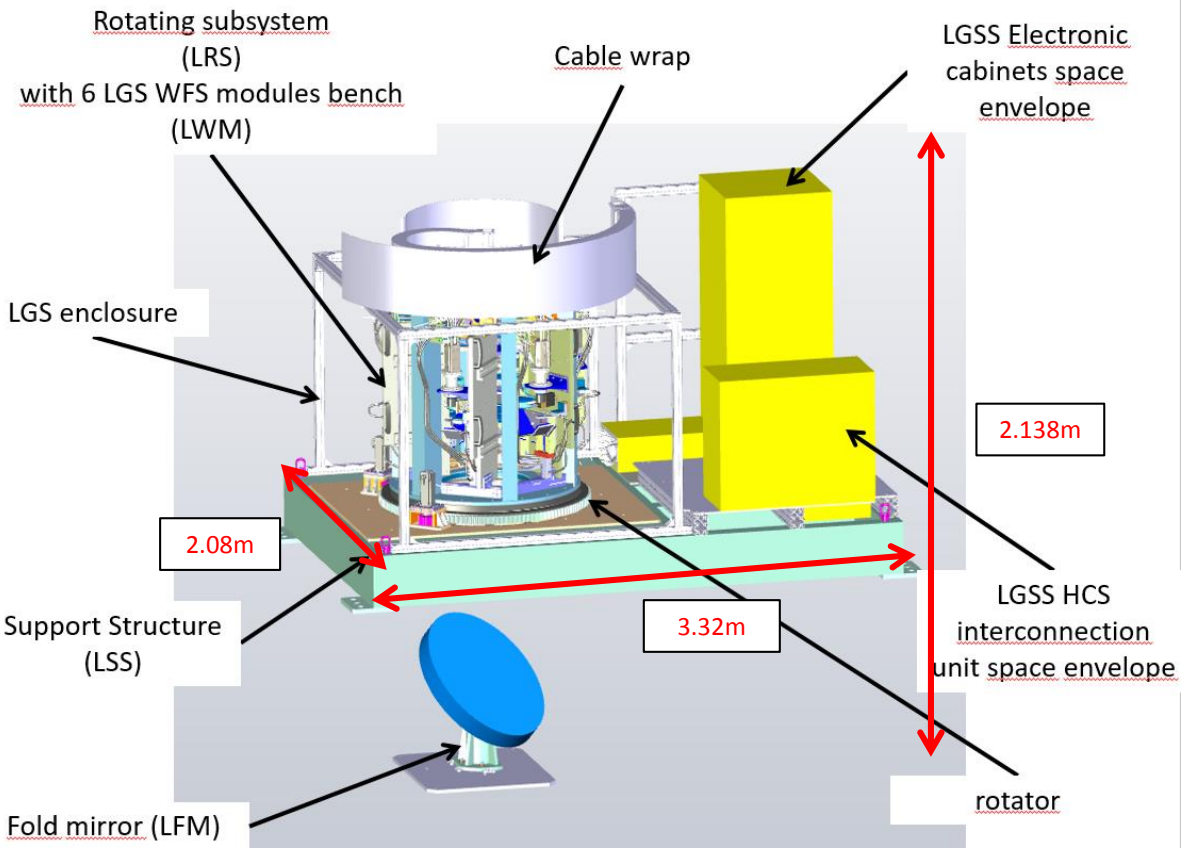
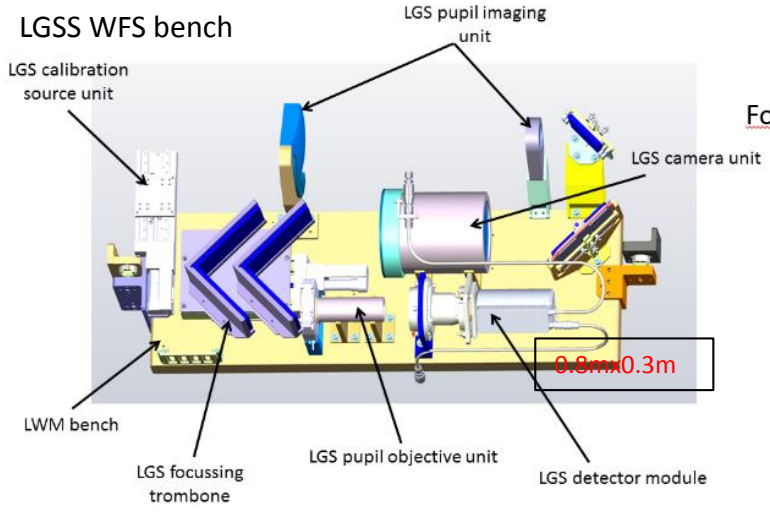
Laser Guide Star Sensors (LGSS)

- Senses high order aberrations from 6 LGS

- System developed under LAM responsability
- Optical and mechanical design by LAM
- Detector Module by IPAG
- Electronics by IAC, but devices selectec by LAM
- AO RTC by Durham





- Six LGSWFS ‘arms’ rotate on common structure
- Rotator and cable wrap under study
- Sensing based on COTS cameras with Sony 1600x1100 pixel detector

Procurement for LGSS:

- Large optics (600x840)
- Freeform optics ; x6 sets
- Other optics – see table

- LGSS WFS camera based on COTS Sony 1600x1100 ; x6 sets

- Cable wrap (60 cables)
- Rotator (diameter ~1.5m)

	PBS number	Diametre in mm	Thickness in mm	Surface Shape	Edges Shapes
LGSS Fold Mirror	123000-0000	600x840		Plane	Elliptical
Pupil Imaging Lens 1	132111-0000	200	40	Plane-convex R1 = infinity R2 = -325.211 mm (freeform) Z6 = - 1.7238.10^{-4} Z7 = - 9.6342.10^{-4} Z11 = 0.075 Z22 = - 7.3204.10^{-4} Z37= - 1.1063.10^{-5} Z56 = - 3.1099.10^{-5} Z79= 7.3937.10^{-6}	Circular Cuted
Pupil Imaging Lens 2	132121-0000	80	20	Meniscal R1 = 120 mm (freeform) Z6 = - 2.3455.10-3 Z7 = - 6.4832.10-4 Z11 = 0.0695 Z22 = - 4.4033.10-4 Z37= - 6.4014.10-4 R2 = 75.675 mm	Circular
Pupil Fold Mirror 1	132131-0000	80x100	20	Plane	Rectangular
Pupil Fold Mirror 2	132141-0000	80x100	20	Plane	Rectangular
CAM 1 Lens	132311-0000	80	15	Meniscal R1 = - 130.502 mm R2 = - 138.769 mm (freeform) Radius norm 40mm Z6 = -1.1619.10-3 Z7 = -1.4388.10-4 Z11 = 1.4817.10-3 Z22 = 1.3422.10-4	Circular
CAM 2 Lens	132321-0000	160	35	Biconvex R1 = 369.590 mm (freeform) Radius norm 95 mm Z6 = -2.6466.10-3 Z7 = 3.7039.10-4 Z11 = -0.143 Z22 = 8.9050.10-3 Z37 = 3.3286.10-3 Z56 = 8.144.10-4 Z79 = 1.0393.10-4 R2 = - 240.755 mm	Circular
V Mirror 1	132411-0000	120x170	20	Plane	Rectangular
V Mirror 2	132421-0000	80x80	20	Plane	Rectangular
Pupil Control Lens	132510-0000	30	4	Convex_Plane R1 = 90 mm R2 = infinity	Circular
LGSS Field Stop	132550-0000	40x40 13.2x13.2 (hole)	200 µm (TBC)	Plane	Square
Pupil Objectif Lens 1	132610-0000	40	5	Plano convex R1 = infinity R2 = 120 mm (aspheric) 2nd :-6.3011.10-4 4th : 2.2715.10-6 6th : 6.8956.10-10	Circular
Pupil Objectif Lens 2	132630-0000	40	5	Meniscus R1 = -87.1876 R2 = -41.9138	Circular
Na Filter	133600-0000	40	5	Plane	Circular

Contact:
Laboratoire d'Astrophysique de Marseille
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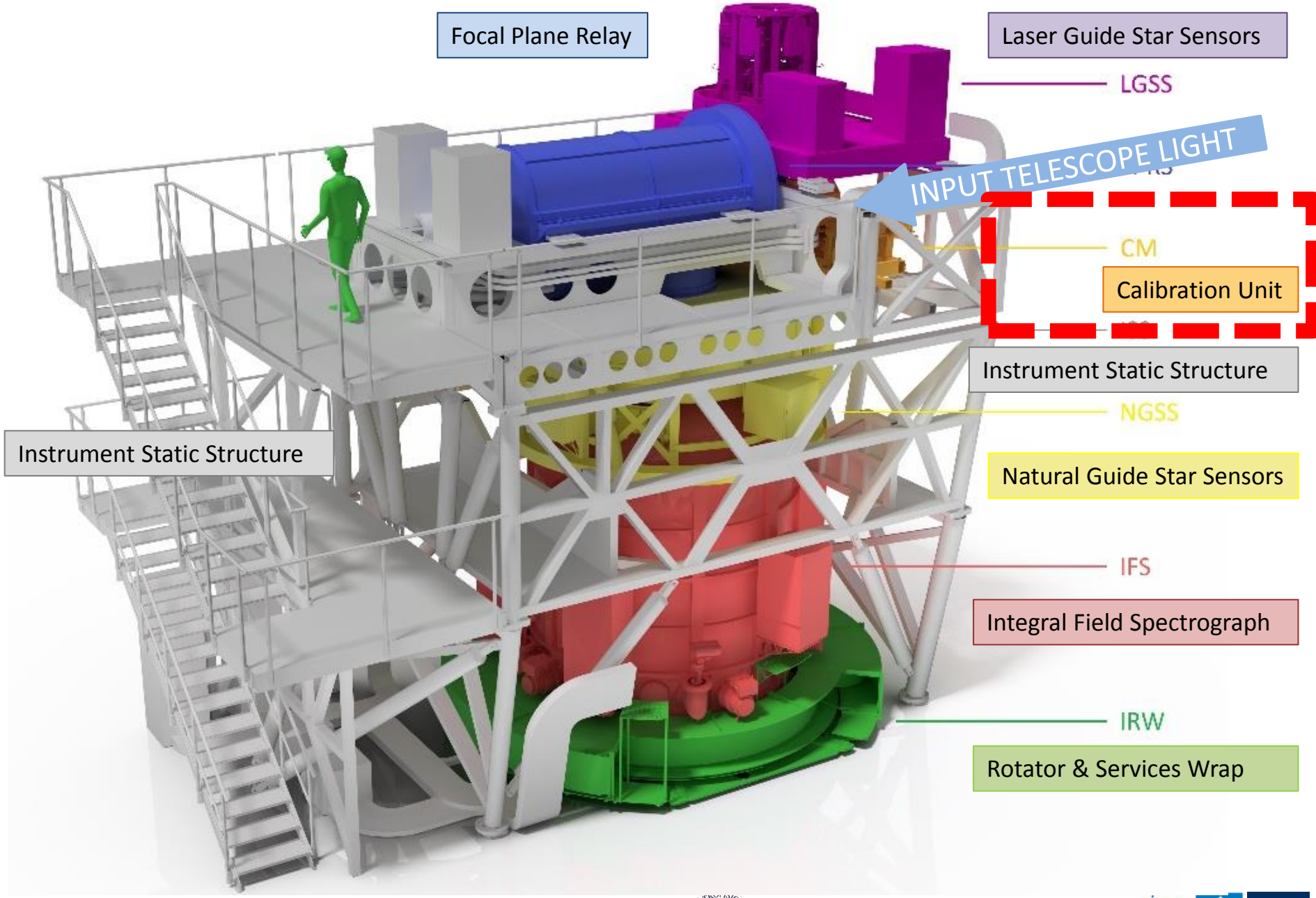
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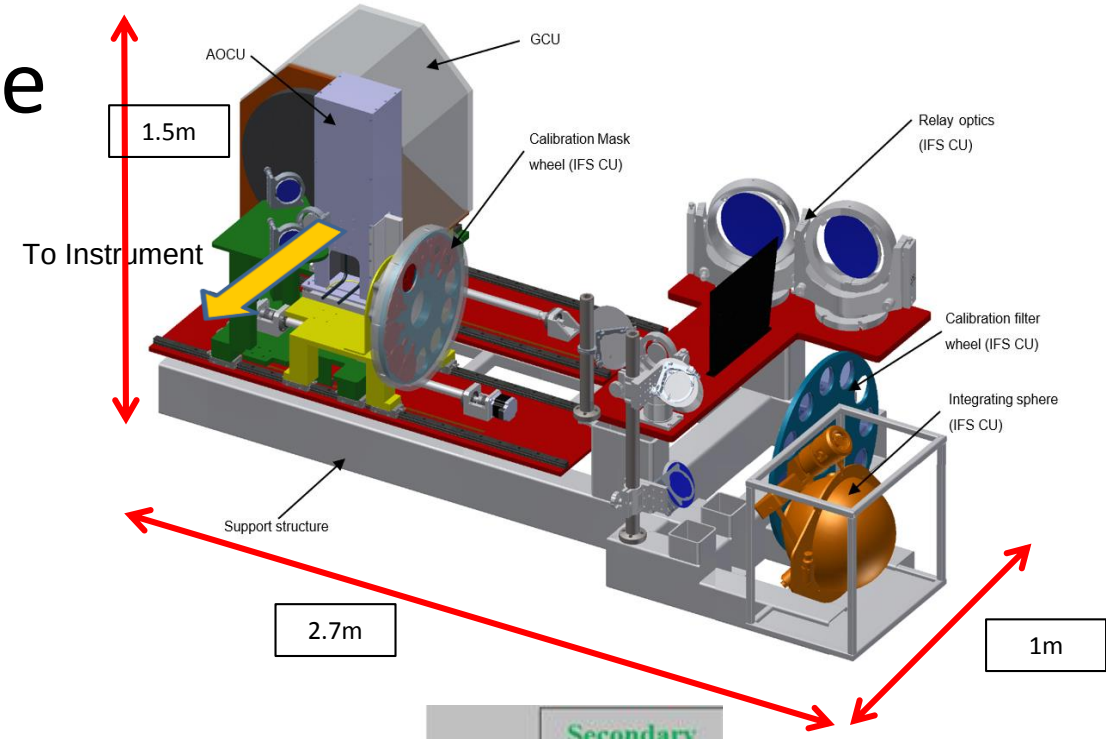
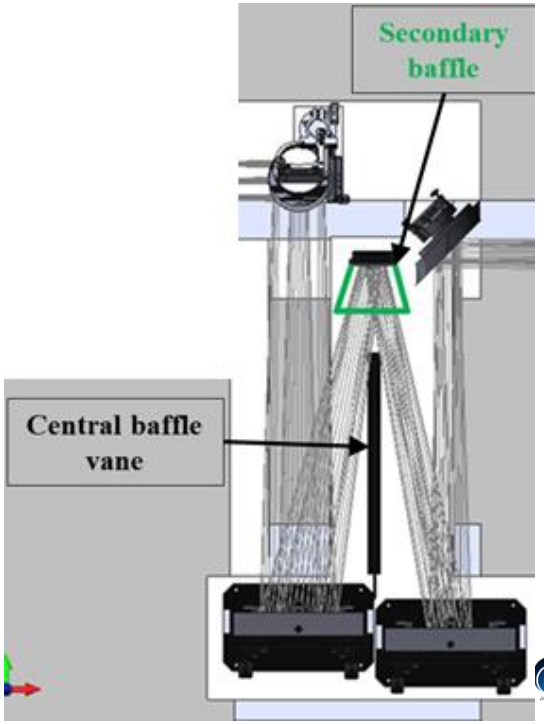
Calibration Module

- Developed by Centro de Astrobiología
- Calibration Module feeds light in at focal plane
- Offner relay for IFS CU
- Aperture stop
- Back pupil reference
- Integrating sphere





Contact:
Centro de Astrobiología (CAB / CSIC-INTA)
Dr. Javier PIQUERAS LOPEZ –
piqueraslj@cab.inta-csic.es

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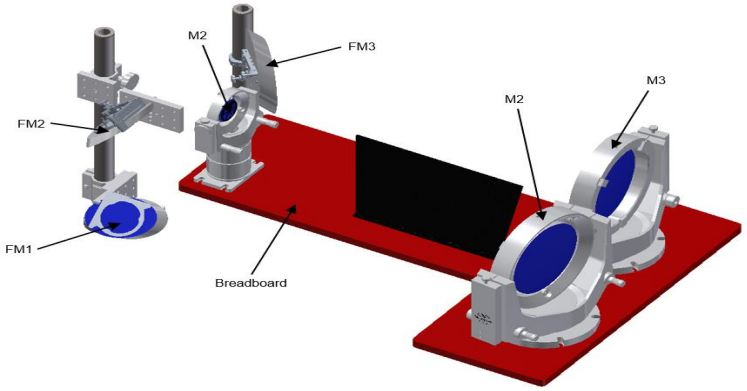
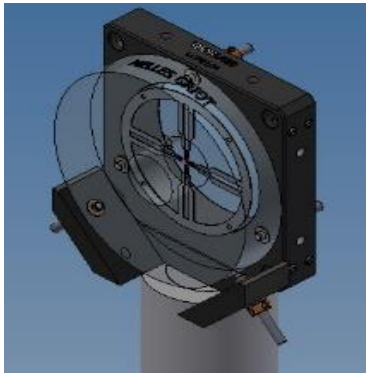
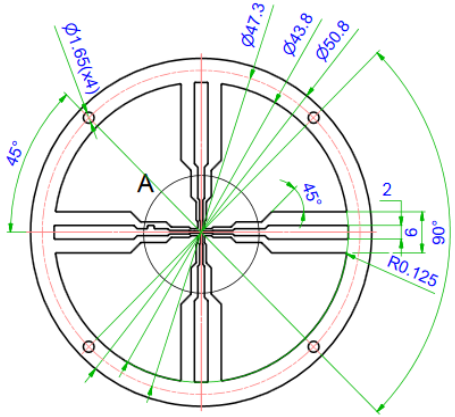
Calibration Unit



- FM1, FM2, FM3, M1, M2, M3 “Mirrors”:
  - Material substrate (Zerodur or Fused Silica)
  - Manufacturing
  - Protected Silver Coating
  - Mechanical support structure of each mirror with Tip/Tilt adjustment
  - Common Baseplate for Offner mounting
  - Complete Offner mirrors assembled and aligned
  - Detailed Re-Alignment procedure
  - Anodized Aluminum baffles

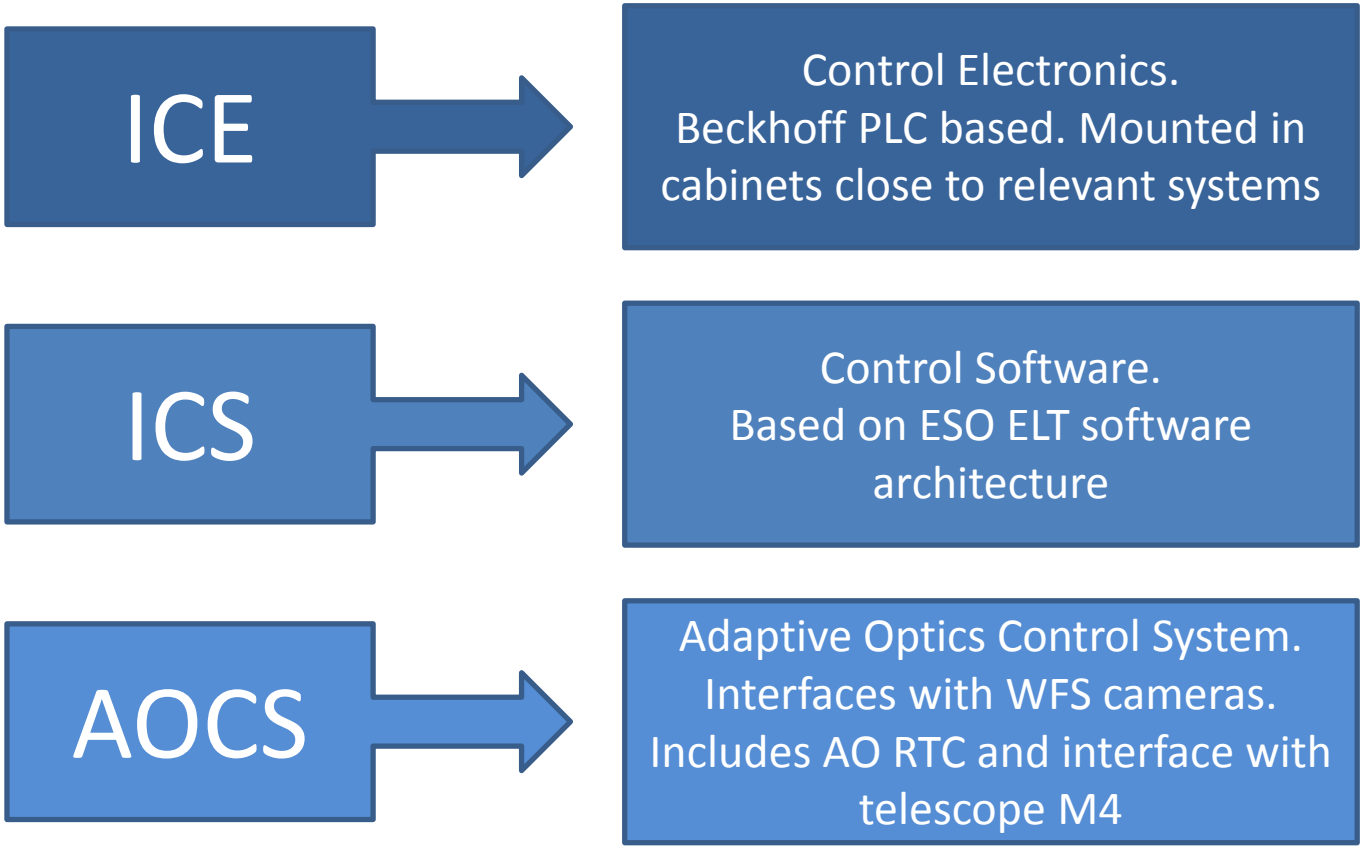


- Mechanical part “Aperture Stop” in front of M2
  - Material (“Stainless Steel black painted” or “Anodized Aluminum”)
  - Manufacturing
  - Assembled and aligned inside Offner for defined Pupil position



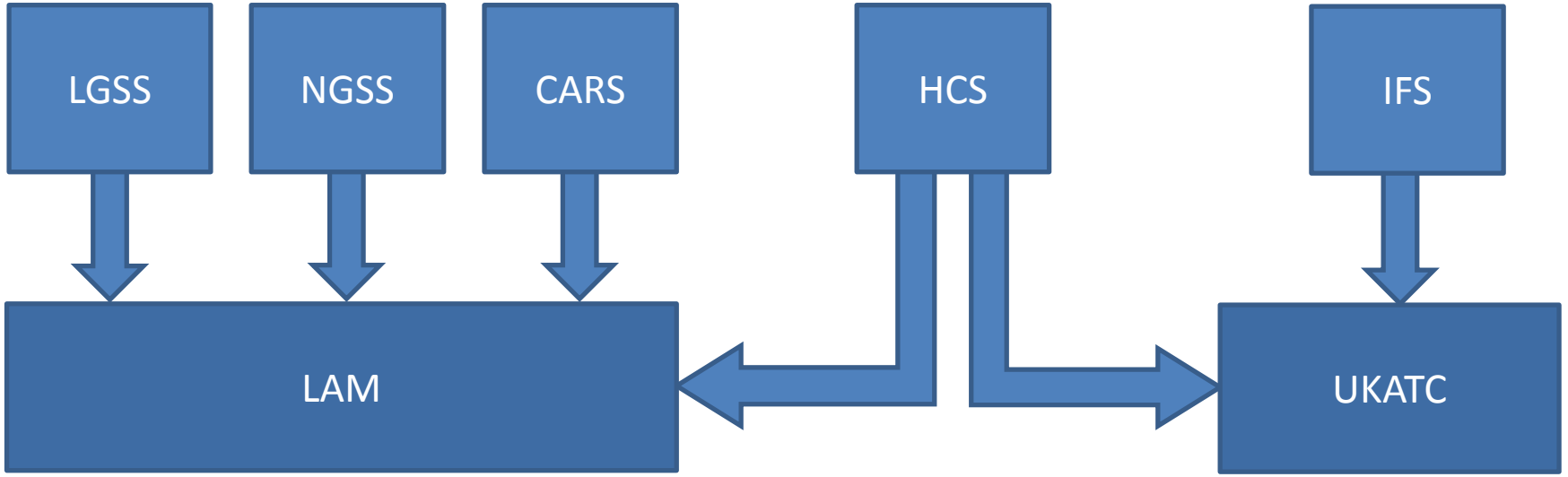
- “Back Pupil Optical Reference”
  - Plane mirror or reflectance glass with defined reference marks for centering.
  - Tip Tilt Mount with XY adjustment capabilities
  - No assembly nor alignment required

HARMONI Control System



Design and delivered products are respecting ESO standards

AIT approach in Europe



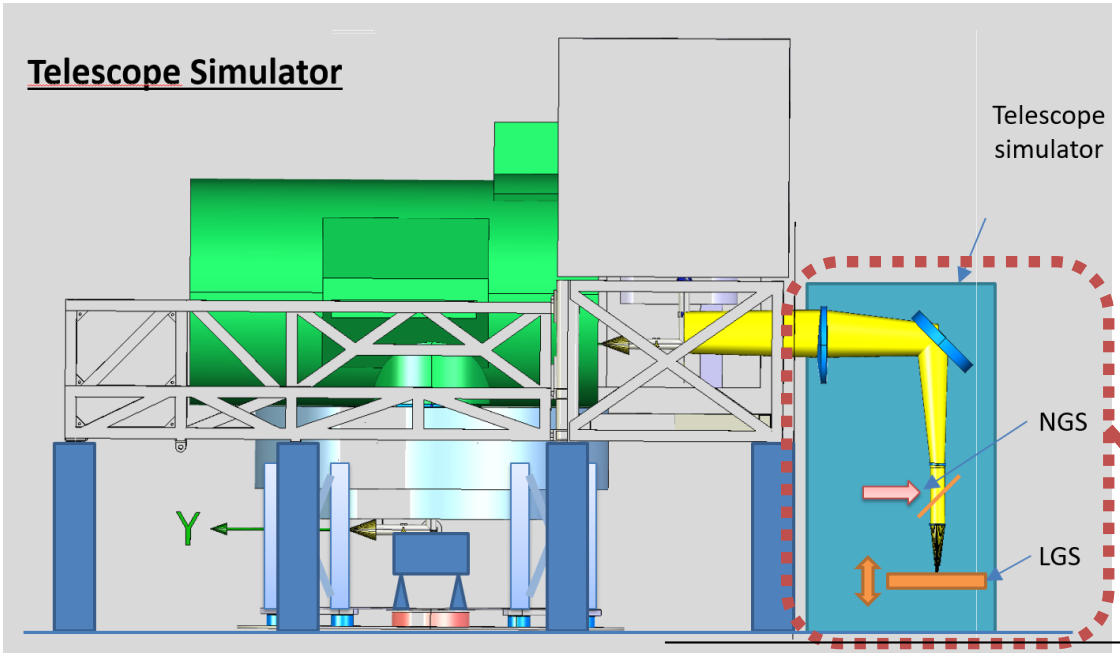
“Top-end” verification

Contact:
Laboratoire d’Astrophysique de Marseille
Dr. Kacem EL HADI - kacem.elhadi@lam.fr

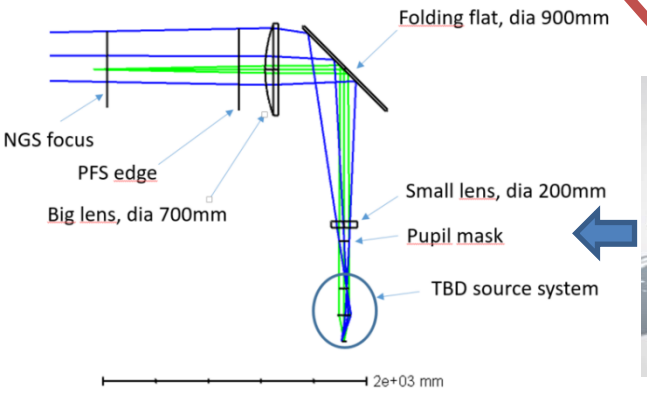
Science Instrument

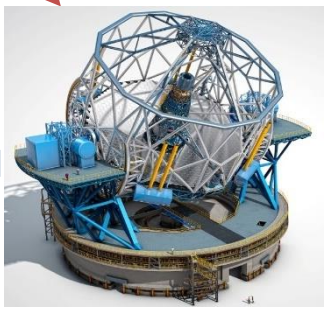
Contact:
UK ATC (Edinburgh)
Mr. William HUMPHREYS – william.humphreys@stfc.ac.uk

Test tools



ELT Telescope simulator





Simulator is made of:

- Natural guide star simulator (x2 NIR) and Laser guide star (no elongation) (x6)
- Deformable mirrors (SLM type) to simulate turbulence and correction (x8)
- Large optical parts

Contact:
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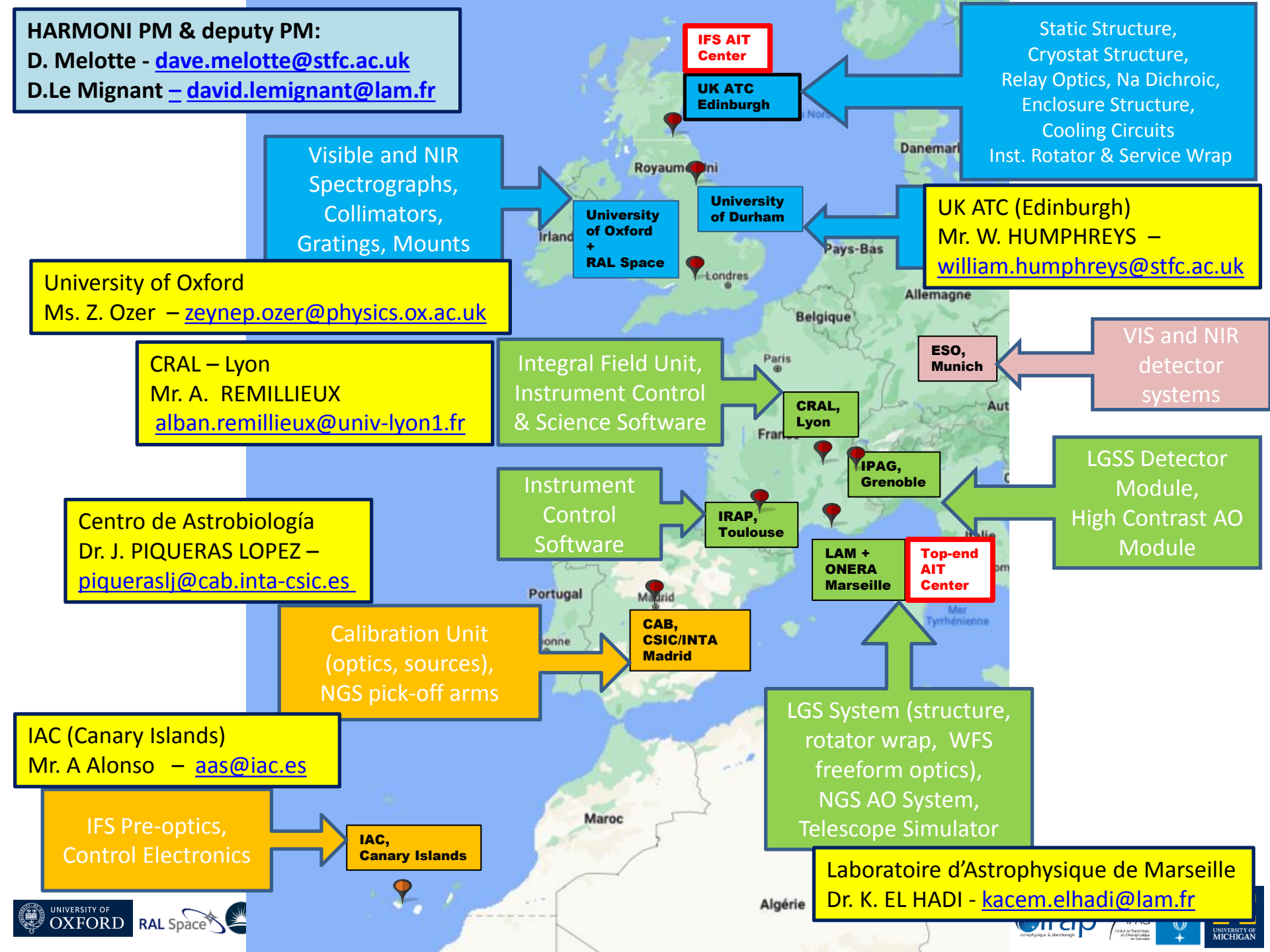
Dr. Kacem EL HADI - kacem.elhadi@lam.fr


HARMONI PM & deputy PM:
D. Melotte - dave.melotte@stfc.ac.uk
D.Le Mignant – david.lemignant@lam.fr
IFS AIT Center
UK ATC Edinburgh
Static Structure,
Cryostat Structure,
Relay Optics, Na Dichroic,
Enclosure Structure,
Cooling Circuits
Inst. Rotator & Service Wrap
Visible and NIR Spectrographs, Collimators, Gratings, Mounts
University of Oxford + RAL Space
University of Durham
UK ATC (Edinburgh)
Mr. W. HUMPHREYS – william.humphreys@stfc.ac.uk
University of Oxford
Ms. Z. Ozer – zeynep.ozer@physics.ox.ac.uk
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alban.remillieux@univ-lyon1.fr
Integral Field Unit, Instrument Control & Science Software
CRAL, Lyon
ESO, Munich
VIS and NIR detector systems
IPAG, Grenoble
LGSS Detector Module, High Contrast AO Module
Instrument Control Software
IRAP, Toulouse
Centro de Astrobiología
Dr. J. PIQUERAS LOPEZ – piqueraslj@cab.inta-csic.es
LAM + ONERA Marseille
Top-end AIT Center
Calibration Unit (optics, sources), NGS pick-off arms
CAB, CSIC/INTA Madrid
LGS System (structure, rotator wrap, WFS freeform optics), NGS AO System, Telescope Simulator
IAC (Canary Islands)
Mr. A Alonso – aas@iac.es
IFS Pre-optics, Control Electronics
IAC, Canary Islands
Laboratoire d'Astrophysique de Marseille
Dr. K. EL HADI - kacem.elhadi@lam.fr
Royaume-Uni
Irlande
Pays-Bas
Belgique
Allemagne
Danemark
Londres
Paris
Portugal
Maroc
Algérie
Mer Tyrrhénienne

Thank you !

Project Partners

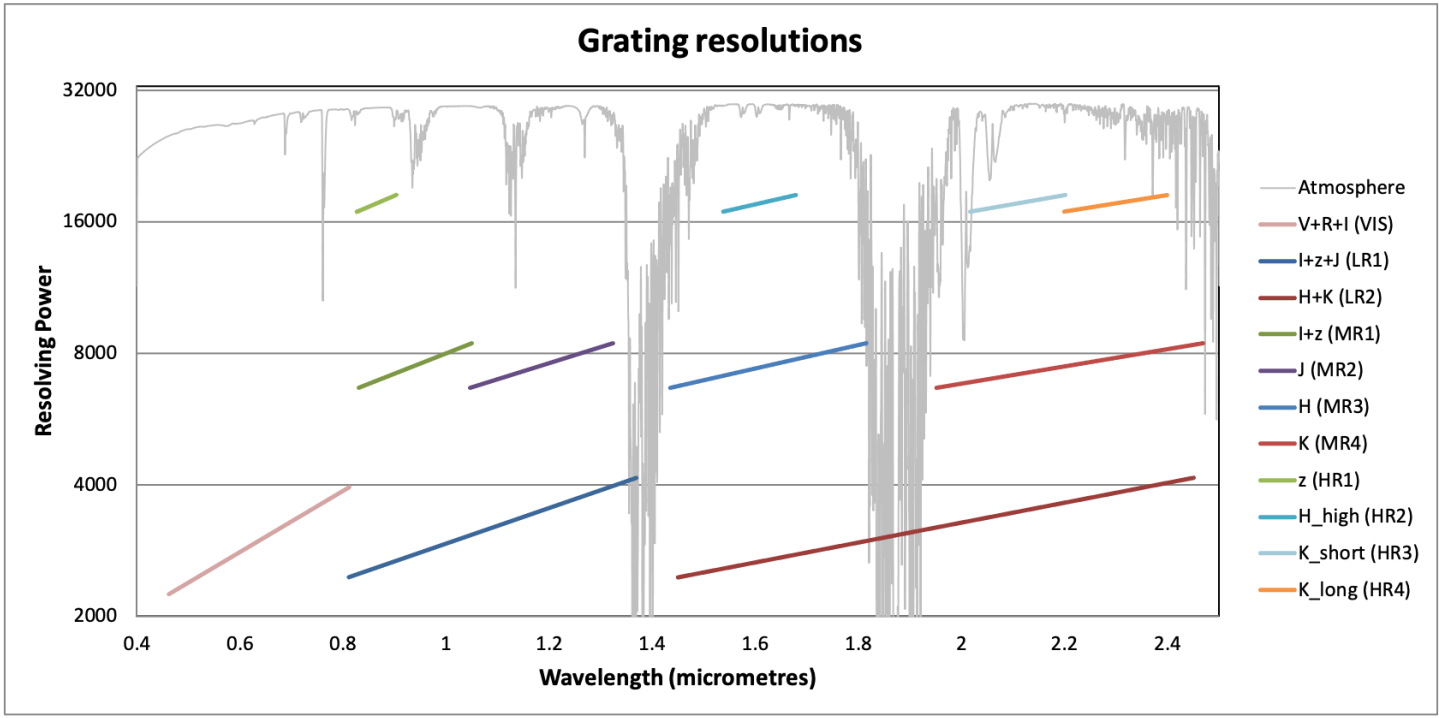
Partner	Location	Work Packages
University of Oxford	Oxford, U.K.	Proj. Management, Spectrographs
UK Astronomy Technology Centre (UKATC)	Edinburgh, U.K.	Cryostat, Focal Plane Relay, IFS AIT, Rotator&Wrap, Static Structure
Laboratoire d'Astrophysique de Marseille (LAM)	Marseille, France	Laser Guide Star System, Single Conjugate AO, Top End AIT
Centre de Recherche Astrophysique de Lyon (CRAL)	Lyon, France	Science Software, Integral Field Unit, Control Software (with EFISOFT)
Durham University	Durham, U.K.	NGS (incl. Sec. Guiding), AO RTC
Centro de Astrobiología (CAB / CSIC-INTA)	Madrid, Spain	Calibration Unit, NGSS Pick-off Arm
Instituto de Astrofísica de Canarias (IAC)	Tenerife, Spain	IFS Pre-optics, Control Electronics

Associate Partners

Associate Partner	Location	Work Packages	Affiliated to
European Southern Observatory (ESO)	Garching, Germany	Detectors and Readout Electronics	
Institut de Planétologie et d'Astrophysique de Grenoble (IPAG)	Grenoble, France	High Contrast System, EFISOFT management	LAM, Marseille
L'Institut de Recherche en Astrophysique et Planétologie (IRAP)	Toulouse, France	Instrument Control Software	EFISOFT
Office National d'Études et de Recherches Aérospatiales (ONERA)	Paris, France	Help with SCAO System & LTAO System Design	LAM, Marseille
Rutherford Appleton Laboratory (RAL-Space)	Harwell, U.K.	Help with Spectrographs design and AIT	Oxford

Spectral layout

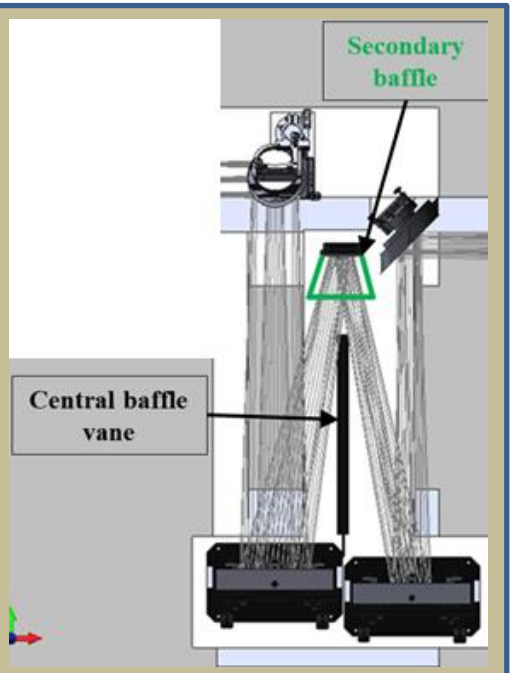
- 3 spectral resolving powers
- All gratings VPHGs in 1st order for maximal efficiency
- VIS and NIR cameras + all reflective design up to disperser

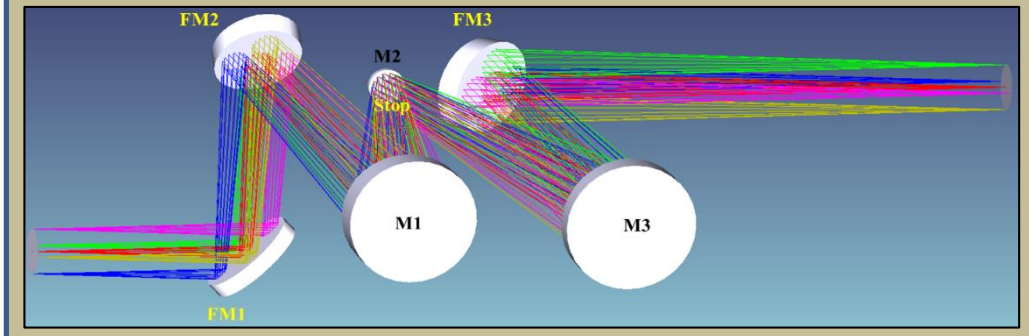


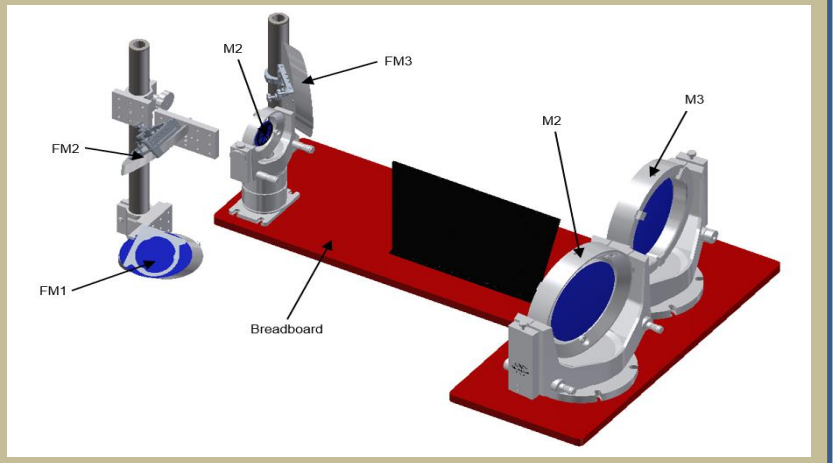
Quotation Request

To be included in quotation:

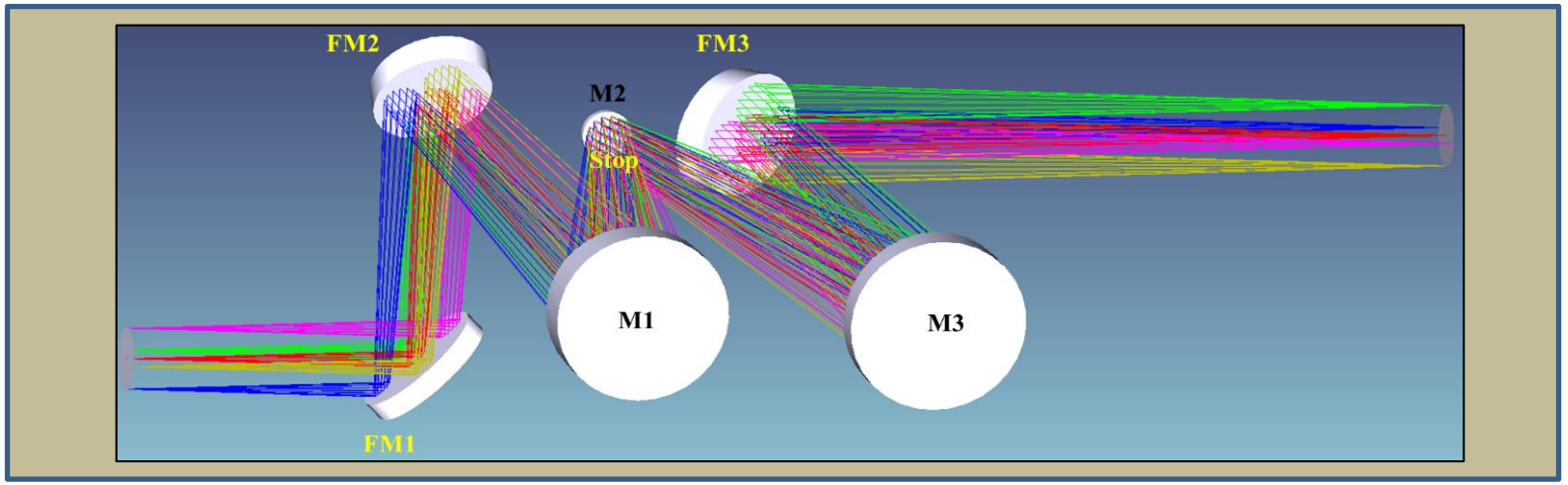
- FM1, FM2, FM3, M1, M2, M3 “Offner Mirrors”:
  - Material substrate (Zerodur or Fused Silica)
  - Manufacturing
  - Protected Silver Coating
  - Mechanical support structure of each mirror with Tip/Tilt adjustment
  - Common Baseplate for Offner mounting
  - Complete Offner mirrors assembled and aligned
  - Detailed Re-Alignment procedure
  - 2x Anodized Aluminum baffles







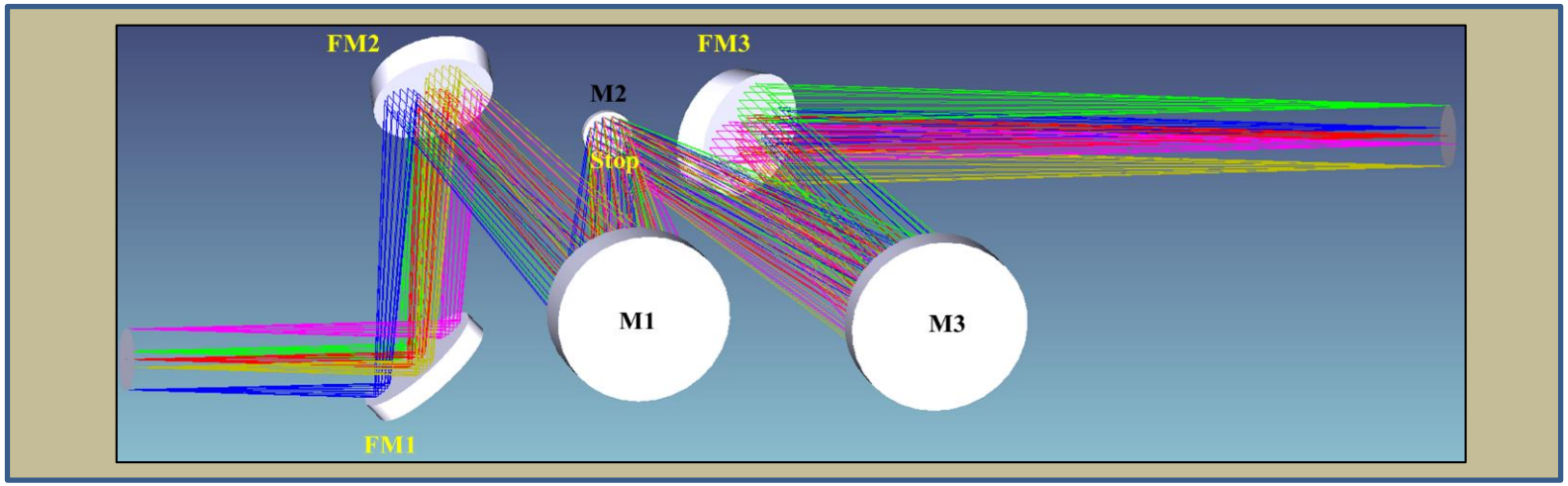
Offner Optical Design



Optical Element	Distance to next element	Type	Radius (mm)	Clear Aperture (mm)	Oversized Aperture (mm)
Object Plane	Off-axis distance: -150mm +504.85	-----	-----	-----	-----
Folding Mirror 1 (FM1)	-140.00	Plane	-----	118.00	126.00
Folding Mirror 2 (FM2)	+900.00	Plane	-----	140.00	148.00
Mirror 1 (M1)	-766.88	Sphere	-1541.10	156.00	164.00
Mirror 2 (M2)	+1.00	Sphere	-771.05	45.00	53.00
Stop	+721.77	-----	-----	45.00	
Mirror 3 (M3)	-585.31	Sphere	-1495.92	148.00	156.00
Folding Mirror 3 (FM3)	+912.52	Plane	-----	152.00	160.00
Imagen Plane	-----	-----	-----	57.00	----

Manufacturing Tolerance in Radius: ± 0.2 mm

Offner Optical Design



Optical Parameter	Value
Image space f/#	17.38
Exit pupil position along the optical axis	-37803.23 mm
Pupil size	2175.1 mm

system Magnification close to -1, - 0.9987.

Pupil positioned by the “Aperture stop”

Required:

Parameter	Value
Image space f/#	17.4
Exit pupil position along the optical axis	-37868 ± 78 mm
Pupil size	2177 ± 5 mm

IFS IRW

- Provides field derotation for IFS+NGSS
- 1.5m diameter bearing + opposing pair drive motors
- Cable wrap carries services for all rotating electronics etc