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Termomeccanica

Mechanical engineering to support the development of the ESO next class of instrumentations

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O.A. CAPODIMONTE - NAPOLI

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RSN 5 - INAF

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Summary

- Introduction to the "Team"
- Team involvement in INAF projects
- Case Study MAORY: design activities and FE Analyses
- System level activities
- Integrated design & CDF

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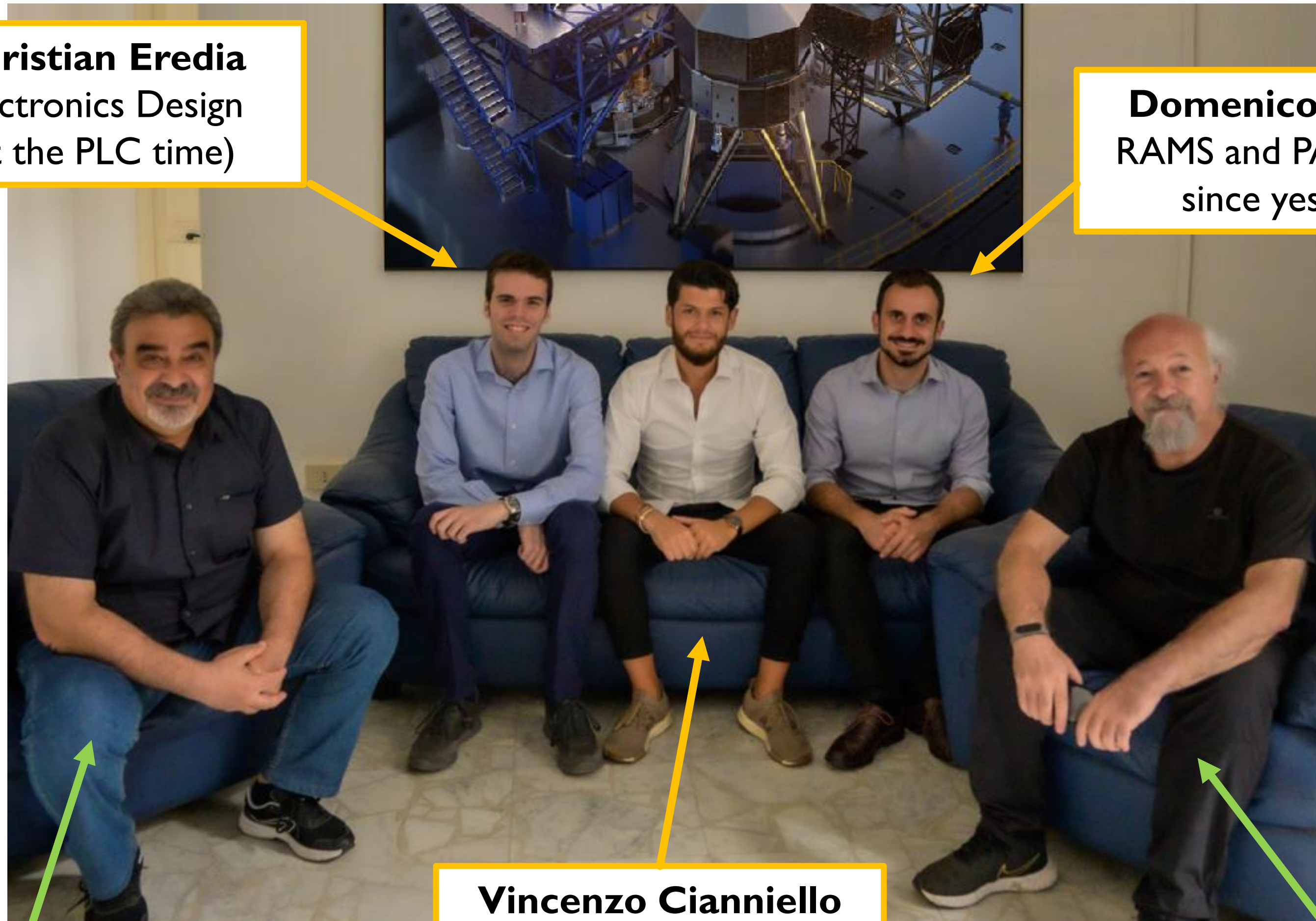
the Team



Christian Eredia
Electronics Design
(at the PLC time)

Domenico D'Auria
RAMS and PA specialist
since yesterday

Vincenzo De Caprio
Mechanical Designer and FEM Analyst (at the ALGOR age)

Vincenzo Cianniello
Mechanical Designer
CAD & FEA expert
(at ANSYS time)

Enrico Cascone
Electronics Design
(at the Maccon age)

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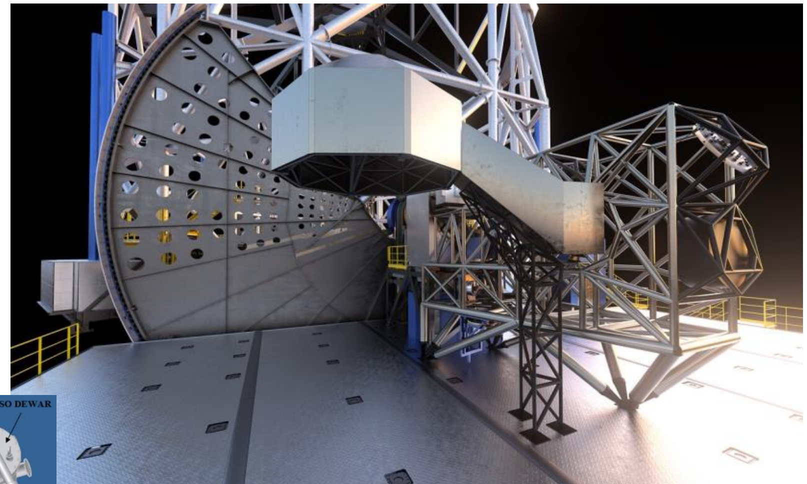
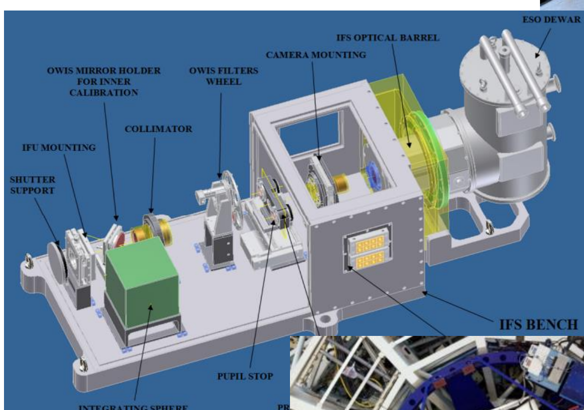
Main projects and activities

Main previous and current projects:

- **MORFEO/MAORY**
- CUBES
- SPHERE+
- ASTRI
- SPHERE-IFS
- X-SHOOTER
- … and so on





Team activities:

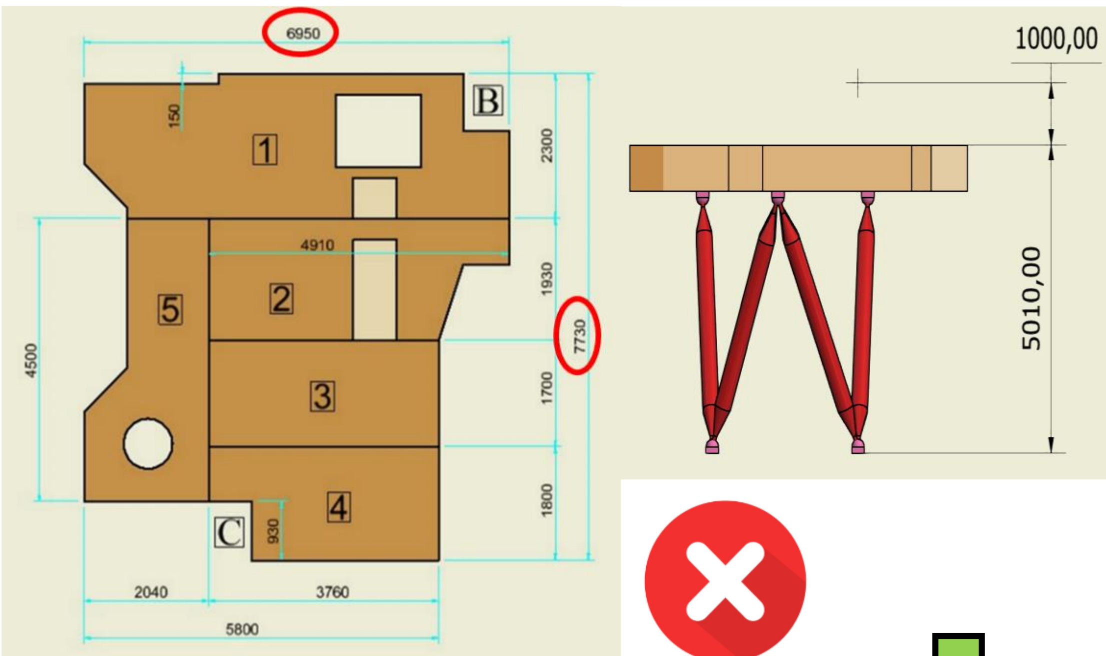
System activities:
- PA/QA
- RAMS
- Requirements
- …

Mechanical design:
- 3D CAD
- FEA Structural validation
- …

Electronics design:
- System architecture
- Control hardware design
- Harness
- …

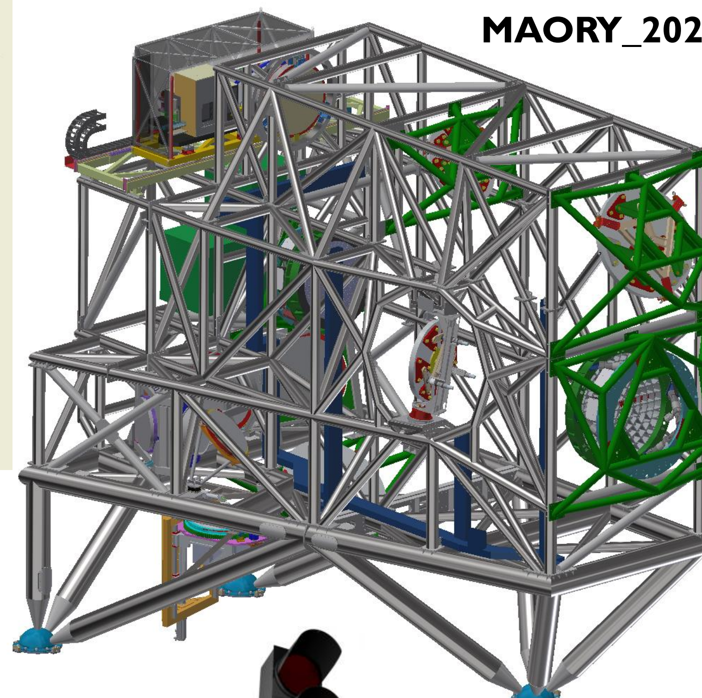
Case study: MAORY

The **MAORY** instrument project entered its phase B in February 2016. Official review (that formally closes this phase) of the Preliminary design is underway, taking into account best scientific performance requirements and interface constraints. MAORY was changed completely during the trade-off consolidation phase (2018-2020), as the images below show.



MAORY_2018 – Phase B
Starting point

MAORY_2021



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Mechanical Design & FEA

The road to the MAORY_2021 mechanical design

Optimization of ratio between global mass and first lowest eigenfrequency of instrument

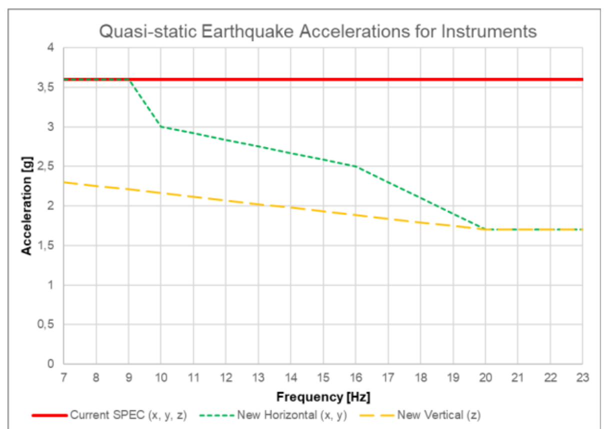
5.2 Eigenfrequencies

[R-INS-1187] /A/ / The lowest eigenfrequency of each Nasmyth and Coude instrument shall be higher than 7Hz. The corresponding analytical verification shall assume infinitely rigid interfaces.

The mother of all requirements

This ESO requirement derives from the **need to decouple** the first frequency of the main structure of the ELT telescope from those of the scientific instruments installed on the Nasmyth platforms at about 30 meters above the ground

The 1st eigenfrequency of instruments defines, also, the specification for setting the earthquake analysis. At experimental level, a correlation between the frequency and the earthquake effects, is noted by ESO. For this reason the accelerations to set are mitigated for the instruments that have the higher first frequency values (as shown below).



INS 1st Eigenfrequency	Quasi-static acceleration		
	Current SPEC (x, y, z)	New Horizontal (x, y)	New Vertical (z)
[Hz]	[g]	[g]	[g]
7	3.6	3.6	2.3
8	3.6	3.6	2.25
9	3.6	3.6	2.21
10	3.6	3.00	2.16
11	3.6	2.92	2.12
12	3.6	2.83	2.07
13	3.6	2.75	2.02
14	3.6	2.67	1.98
15	3.6	2.58	1.93
16	3.6	2.50	1.88
17	3.6	2.30	1.84
18	3.6	2.10	1.79
19	3.6	1.90	1.75
20	3.6	1.7	1.7
21	3.6	1.7	1.7
22	3.6	1.7	1.7
23	3.6	1.7	1.7

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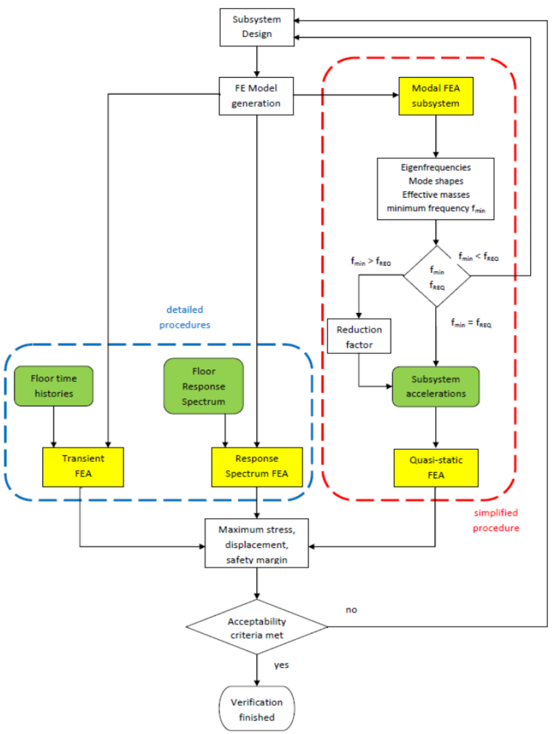
Mechanical Design & FEA

The FEA settings for earthquake analysis → the worst survival condition for instruments



1) $f_{min} < f_{REQ}$: The subsystem eigenfrequency requirement is not met. Redesign of the subsystem is necessary.

2) $f_{min} = f_{REQ}$: The subsystem eigenfrequency requirement is met. The quasi-static subsystem accelerations shall be applied to the subsystem structure.

3) $f_{min} > f_{REQ}$: The subsystem eigenfrequency requirement is met. The quasi-static subsystem accelerations may be multiplied with the appropriate reduction factor before it is applied to the subsystem structure.

By using the structural FE Model of the subsystem the static deformations and stresses shall be analysed. The maximum action effect (AEd1, AEd2, and AEd3) due to the three orthogonal seismic acceleration components shall be calculated with the Percentage Combination Rule:

a) AEd1 = ± Edx ± 0.3*Edy ± 0.3*Edz

b) AEd2 = ± 0.3*Edx ± Edy ± 0.3*Edz

c) AEd3 = ± 0.3*Edx ± 0.3*Edy ± Edz

where "±" means "to be combined with"

Edx Quasi-static earthquake acceleration in the x-direction

Edy Quasi-static earthquake acceleration in the y-direction

Edz Quasi-static earthquake acceleration in the z-direction.

The maximum seismic action effect due **AEd** is the worst case of all the possible load combinations:

AEd = max (AEd1, AEd2, AEd3)

In the following chart are showed the starting accelerations values for Nasmyth instruments, highlighted by the yellow rectangle, for the earthquake analysis.

The force exerted by any of the Nasmyth instruments on any attachment point shall not exceed a maximum load of:

- Force: 500 kN in the X_{Az} and Y_{Az} directions
- Force: 1000 kN tensile and 1250 kN compression in the Z_{Az} directions

this shall apply in any operational configuration and any survival condition (NCR, earthquake loads, wind load, etc.).

The flanges shall be loaded with the forces directed to the centre of the flanges in order to avoid local moments. The maximum eccentricity of loads as defined in EN 1998-1-8 section 2.7 shall be <10% of the width of the flange.

For the calculation of the forces on the flanges safety factor SF = 1.3, according to AD7, shall be considered in all load cases, including survival and accidental load cases.

Load case n°	Acceleration X Component	Acceleration Y Component	Acceleration Z Component	Maximum displac.	Maximum Equivalent von Mises Stress
	mm s^-2	mm s^-2	mm s^-2	mm	MPa
1	32361,78	9708,53	16229,92	4,46	269,21
2	32361,78	9708,53	3383,28	4,21	230,09
3	32361,78	-9708,53	16229,92	9,10	323,45
4	32361,78	-9708,53	3383,28	8,85	277,86
5	-32361,78	9708,53	16229,92	8,48	209,43
6	-32361,78	9708,53	3383,28	8,72	254,05
7	-32361,78	-9708,53	16229,92	4,03	194,98
8	-32361,78	-9708,53	3383,28	4,12	209,58
9	9708,53	32361,78	16229,92	12,04	282,86
10	-9708,53	32361,78	16229,92	14,21	242,75
11	9708,53	32361,78	3383,28	12,15	243,84
12	-9708,53	32361,78	3383,28	14,39	259,61
13	9708,53	-32361,78	16229,92	14,70	328,14
14	-9708,53	-32361,78	16229,92	12,40	206,39
15	9708,53	-32361,78	3383,28	14,50	283,08
16	-9708,53	-32361,78	3383,28	12,23	223,39
17	9708,53	9708,53	31234,02	3,32	200,17
18	9708,53	-9708,53	31234,02	5,84	235,47
19	-9708,53	9708,53	31234,02	4,99	206,73
20	-9708,53	-9708,53	31234,02	3,45	210,82
21	9708,53	9708,53	-11620,82	3,20	98,77
22	9708,53	-9708,53	-11620,82	5,07	98,72
23	-9708,53	9708,53	-11620,82	5,46	165,02
24	-9708,53	-9708,53	-11620,82	3,14	139,95
MAX value				14,7	328,14

Mechanical Design & FEA

FEA to check the instrument stability → the operational condition: wind + Nasmyth Distortion

Wind Analysis

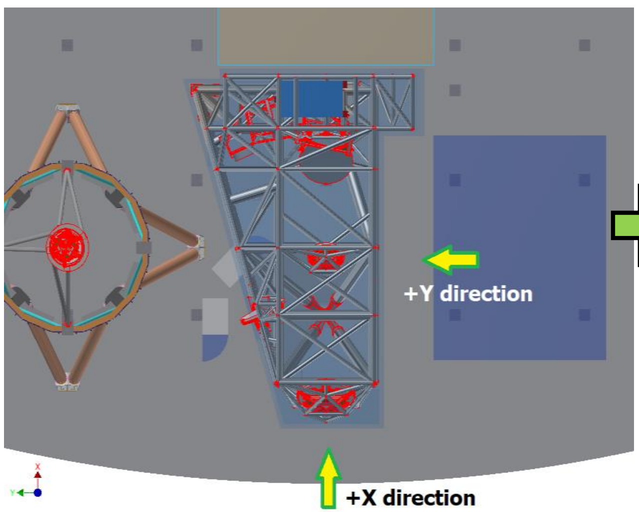
For both the cases the Main Support Structure shall perform a wind induced distortion analysis considering the average wind speed and the air density in the following directions (separately), as shown in Figure below:

- +Y, acting on the right side of MAORY
- +X, acting on the external side of MAORY

The external loads are evaluated starting from the wind speed and computing the **aerodynamic resistance** of the structure (**R**ₐ), through the formula:

$$R_a\ [N] = \frac{1}{2} \rho v^2 \times A_{sect} \times C_R$$

- **ρ** is the air density [kg/m3]
- **v** is the average wind speed [m/s]
- A_{sect} is the area of the normal section (⊥ to the direction of the loads)
- C_R is the drag coefficient for the reference area against with the wind flows



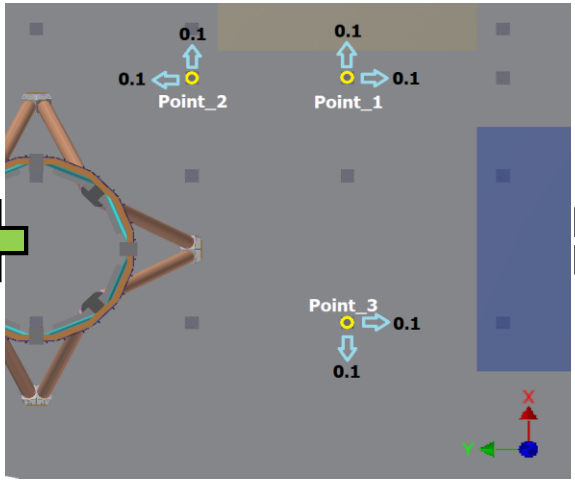
Nasmyth Induced Distortion Analysis

The Induced Distortion Analysis studies the impact of the distortions of the Nasmyth platform on the MAORY MSS. It is carried out imposing the specific boundary conditions on the attachment points, i.e. a set of the imposed displacements on the FE constraints between the NP and the MSS.

Basing on the Static Analysis and according to the Main Structure Technical Specifications (AD6), the Nasmyth Induced Distortion Analysis is performed just for the MSS. To verify the compliance with Tech Spec just one simplified analyses (according to AD9) is required.

Starting from the displacements defined in the following list and showed in Figure below, the outputs for the Nasmyth Induced Distortion Analysis, i.e. the displacements and rotations of each optomechanical elements, are used to check the stability of the system.

- **Point_1** → Dx 0.1mm, Dy -0.1mm, Dz 0mm
- **Point_2** → Dx 0.1mm, Dy 0.1mm, Dz 0mm
- **Point_3** → Dx -0.1mm, Dy -0.1mm, Dz 0mm

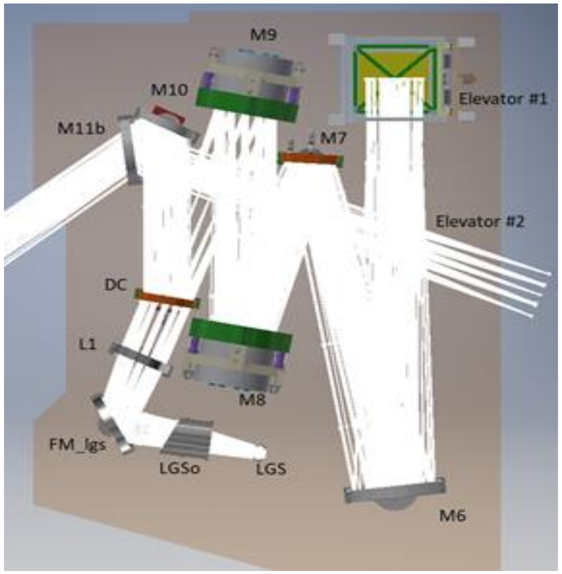


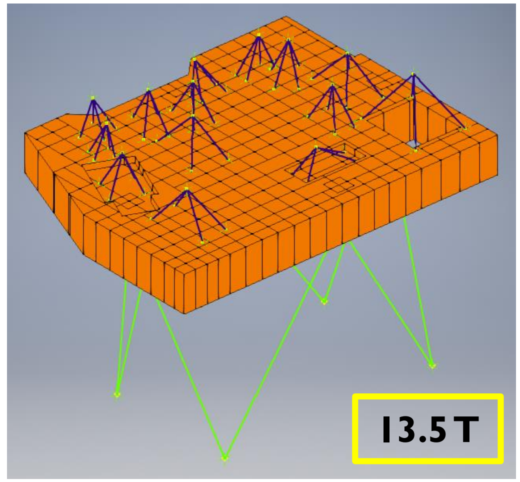
	INDUCED DISPLACEMENT+ Δ OPERATIONAL WIND (X+)	INDUCED DISPLACEMENT+ Δ OPERATIONAL WIND (Y+)
Deformation Probe SP X Axis	0,019101769	0,018509082
Deformation Probe SP Y Axis	0,115710247	0,117286522
Deformation Probe SP Z Axis	-0,022807181	-0,02254802
Deformation Probe M6 X Axis	0,034632351	0,033759218
Deformation Probe M6 Y Axis	0,113468219	0,115717597
Deformation Probe M6 Z Axis	-0,022460669	-0,022060305
Deformation Probe M7 X Axis	0,026260358	0,026003321
Deformation Probe M7 Y Axis	-0,003495478	-0,003232966
Deformation Probe M7 Z Axis	-0,028258115	-0,028117001
Deformation Probe M8 X Axis	0,039611466	0,039010167
Deformation Probe M8 Y Axis	0,09977185	0,101987101
Deformation Probe M8 Z Axis	0,030648381	0,030483782
Deformation Probe M9/DM1 X Axis	0,008764654	0,008353099
Deformation Probe M9/DM1 Y Axis	0,041463688	0,042356208
Deformation Probe M9/DM1 Z Axis	-0,02354598	-0,023325264
Deformation Probe M10/DM2 X Axis	0,017472439	0,017040573
Deformation Probe M10/DM2 Y Axis	0,040510856	0,04199034
Deformation Probe M10/DM2 Z Axis	0,033809125	0,033635795
Deformation Probe DC+FM1 X Axis	0,019314274	0,019003749
Deformation Probe DC+FM1 Y Axis	0,045648692	0,046081772
Deformation Probe DC+FM1 Z Axis	-0,025800213	-0,025649875
Deformation Probe M11 X Axis	0,036056396	0,035650488
Deformation Probe M11 Y Axis	0,024650667	0,025730078
Deformation Probe M11 Z Axis	-0,067812324	-0,068263918
Deformation Probe SP X Axis	-0,002254421	-0,002275237
Deformation Probe SP Y Axis	0,000760937	0,000756934
Deformation Probe SP Z Axis	0,000523071	0,000528634
Deformation Probe M6 X Axis	-0,002404916	-0,002415795
Deformation Probe M6 Y Axis	0,000601004	0,000612715
Deformation Probe M6 Z Axis	0,000251547	0,000242292
Deformation Probe M7 X Axis	-0,002479568	-0,002485704
Deformation Probe M7 Y Axis	-0,000265841	-0,000265501
Deformation Probe M7 Z Axis	-2,941E-05	-2,88149E-05
Deformation Probe M8 X Axis	-0,001866929	-0,001885174
Deformation Probe M8 Y Axis	0,000445805	0,000435556
Deformation Probe M8 Z Axis	0,000382072	0,000382223
Deformation Probe M9/DM1 X Axis	-0,002110273	-0,002124838
Deformation Probe M9/DM1 Y Axis	-8,56992E-05	-9,01332E-05
Deformation Probe M9/DM1 Z Axis	0,000199099	0,000203027
Deformation Probe M10/DM2 X Axis	-0,001900749	-0,001921111
Deformation Probe M10/DM2 Y Axis	0,001004131	0,000994613
Deformation Probe M10/DM2 Z Axis	0,000393265	0,000392393
Deformation Probe DC+FM1 X Axis	-0,002399256	-0,002407717
Deformation Probe DC+FM1 Y Axis	-0,000207826	-0,0002098
Deformation Probe DC+FM1 Z Axis	0,000155291	0,000152247
Deformation Probe M11 X Axis	-0,002588674	-0,0026018
Deformation Probe M11 Y Axis	0,005870392	0,005855466
Deformation Probe M11 Z Axis	0,000440122	0,000434298
	MAX	MAX
	0,115710247	0,117286522

In order to evaluate the **stability under operational conditions of the MAORY MSS**, the contributes of the Nasmyth Induced Distortion Analysis and the Wind analysis (under operational conditions) have been summed along X+ and Y+ separately.

Mechanical Design & FEA

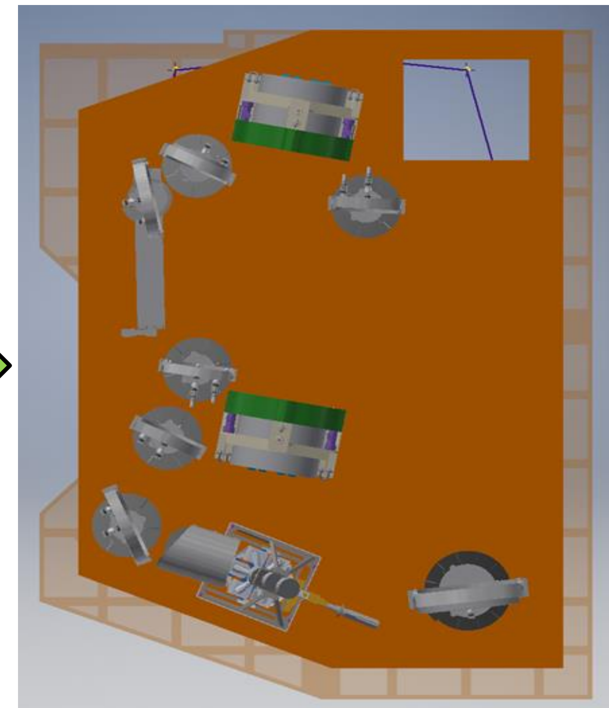
The road to the MAORY_2021 mechanical design
Optimization of ratio between global mass and first lowest eigenfrequency of instrument





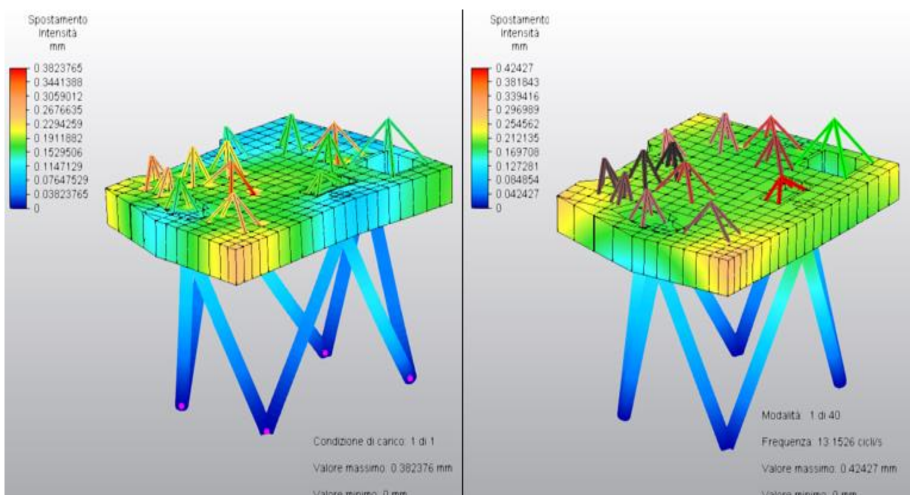
FE model with Optomechanical mass points

Aspherical Mirror Configuration (AMC) optical path



MAORY_2019_Type_2

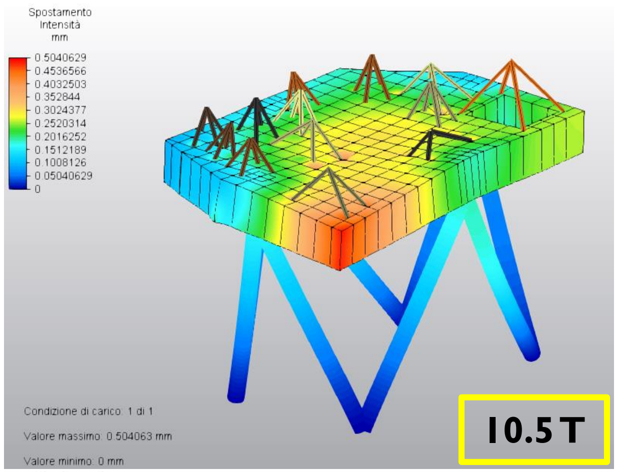
MAORY_2019_Type_1

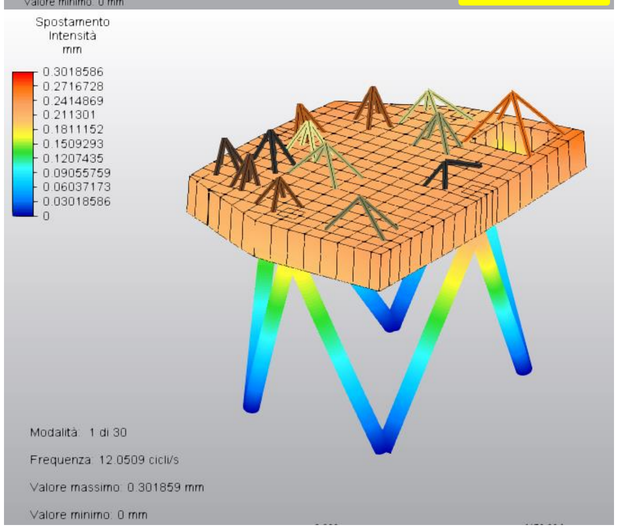


Mechanical Design & FEA

The road to the MAORY_2021 mechanical design

This mechanical configuration represents the best result for MAORY steel plate bench.



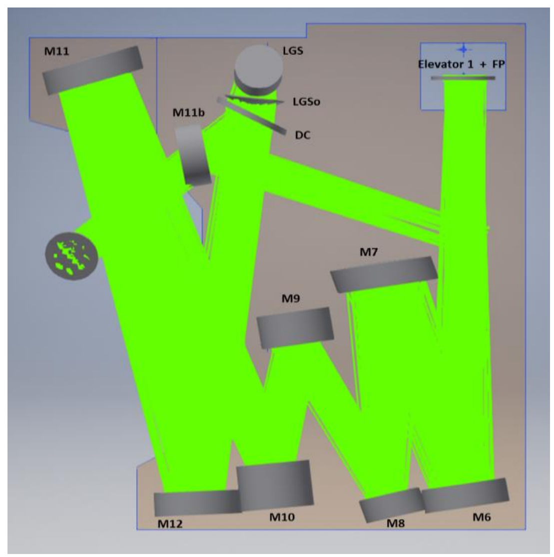


FEA Results Type_2
Static and Modal Analysis

The optical evolutions of the system in order to optimize the performances of the instrument imposed a change of the optical path, leading to a new bigger configuration…

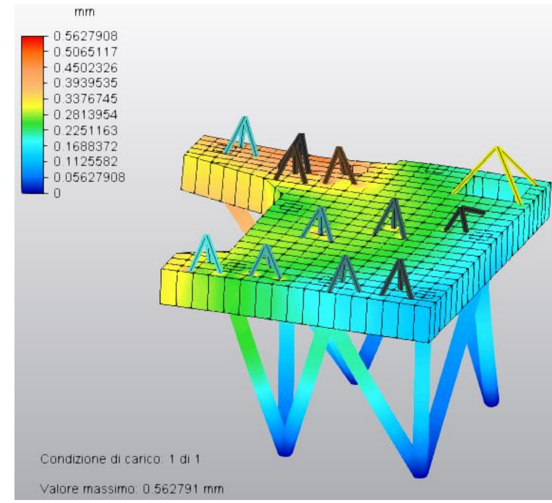
Adding problems under a mechanical point of view…!!

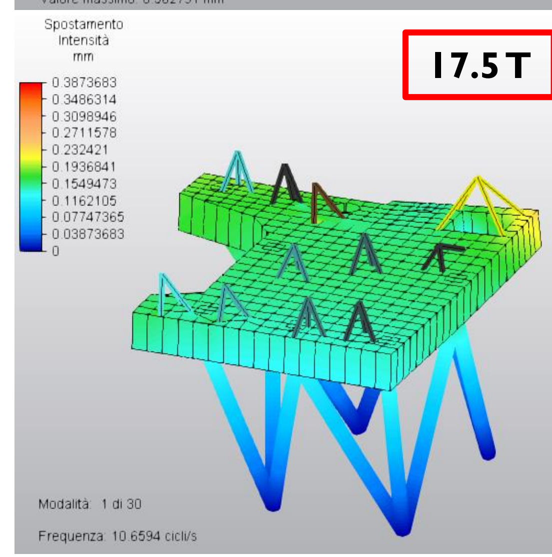
In this period the requirement on the mass was also under review by ESO → other problem…



Modified Offner Configuration (MOC) optical path

FEA Results MOC_Type_1
Static and Modal Analysis



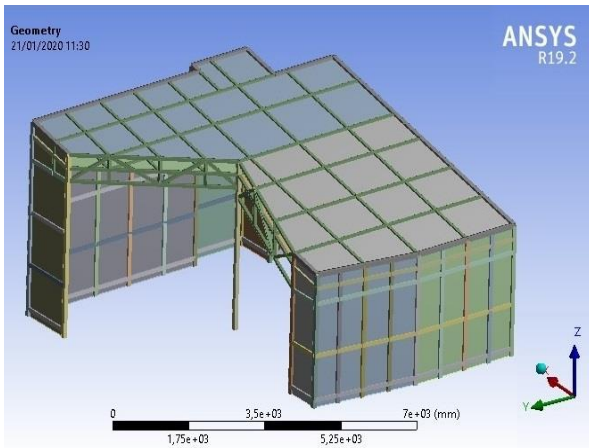


Mechanical Design & FEA

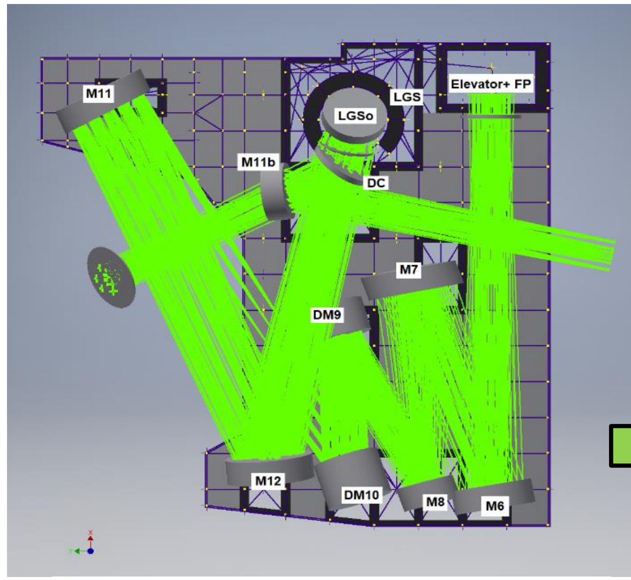
The road to the MAORY_2021 mechanical design

It is clear that applying the same design philosophy did not provide encouraging results → **it was necessary to change something significant … !!**

For the same optical configuration, with small modifications, the new mechanical design was developed → the "spatial reticular structure"

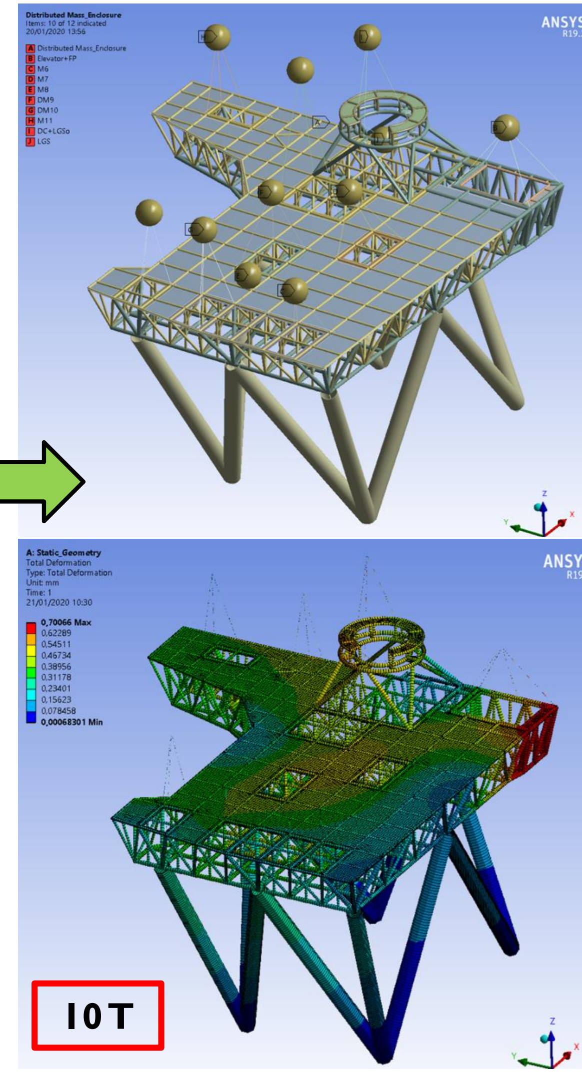


A thermal enclosure was also developed for this configuration



Name	x [mm]	y [mm]	z [mm]	Mass [kg]	Mass with 20% [kg]
Elevator + FP	398	0	0	1000 + 230	1500
M6	-6731	0	0	511	613
M7	-3094	1179	0	624	749
M8	-6681	1059	0	340	408
DM9	-3856	2401	0	1000	1200
DM10	-6265	2306	415	1000	1200
DC+LGSo	-739	2260	1868	860	1032
M11	-88	6055	424	623	748
M12	-6249	3518	423	556	667
M13b	-1604	3194	1306	606	727
LGS	-414	2177	-200	700	840
				8050	9684
Thermal Cover	**without contincency**			3600	3600
				TOTAL	13284

MAORY_MOC_Type_2
FE model and payload



This mechanical solution allows to obtain a net gain of at least 5T → MISSION COMPLETE

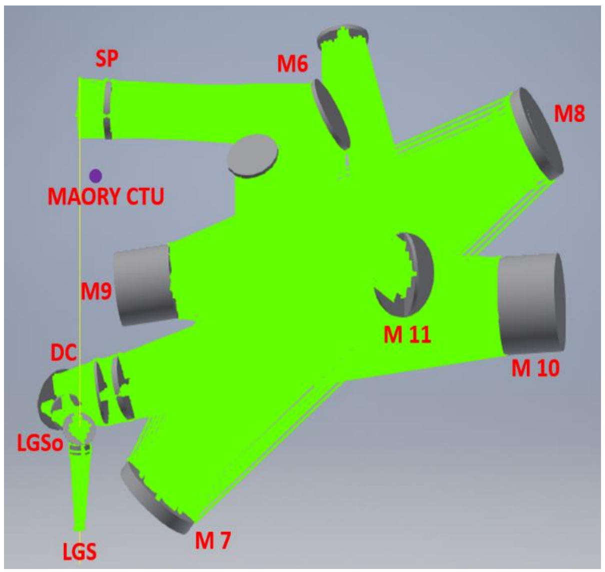
Mechanical Design & FEA

The road to the MAORY_2021 mechanical design

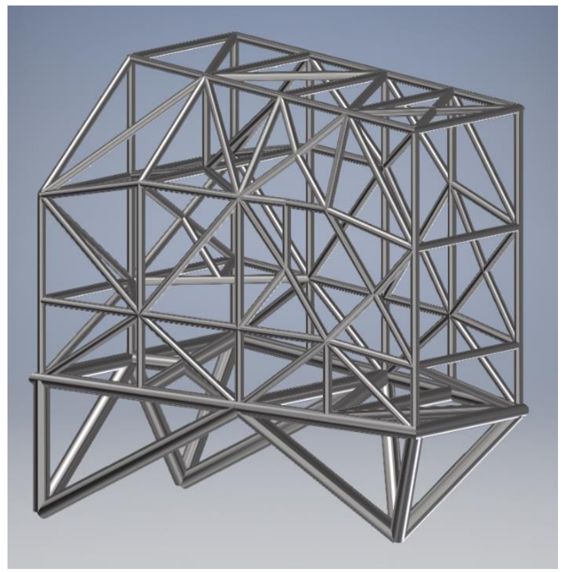
But an optical trade-off with a promising vertical configuration (MMC) put us in front of an unprecedented challenge ...

To develop an innovative "vertical" optical bench ...

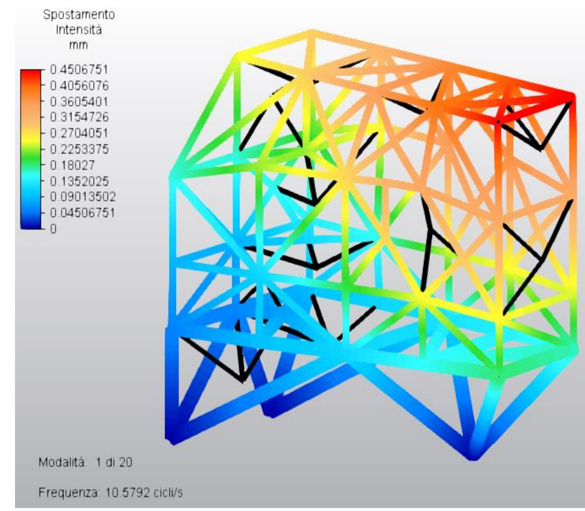
MAORY Mirror Configuration (MMC) optical path

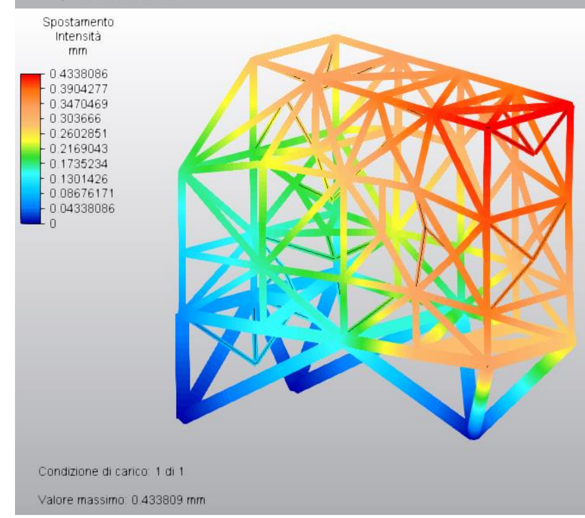


MAORY_MMC_Type_I



8,5 T

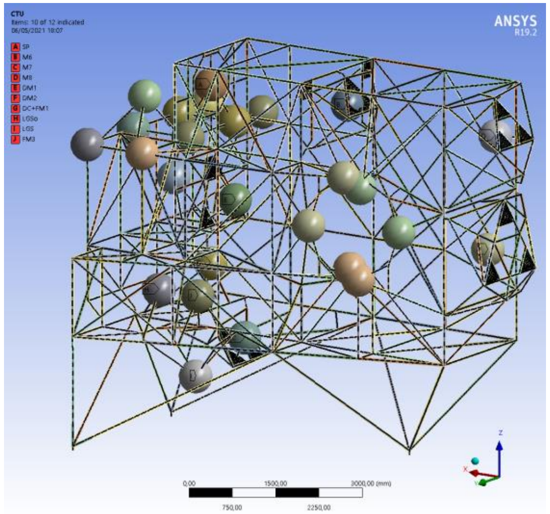


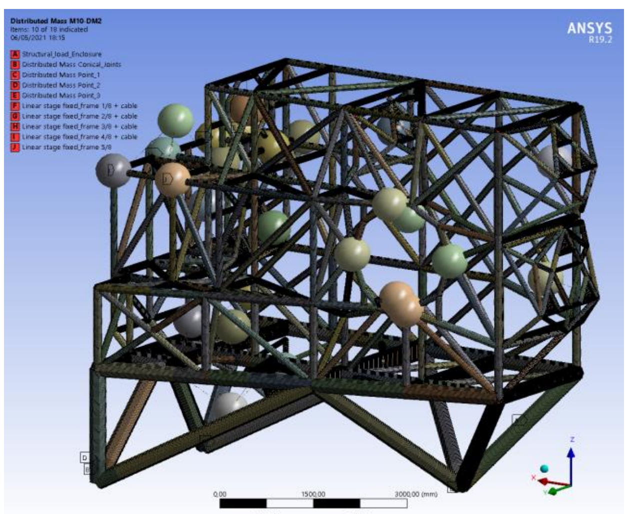


FEA Results MAORY_MMC Type_I
Static and Modal Analysis

Mechanical Design & FEA

The road to the MAORY_2021 mechanical design





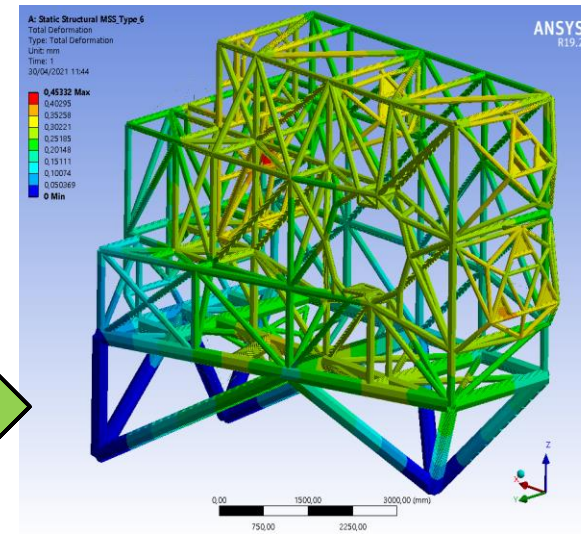
MAORY_MSS_Type_6 Meshed FE model

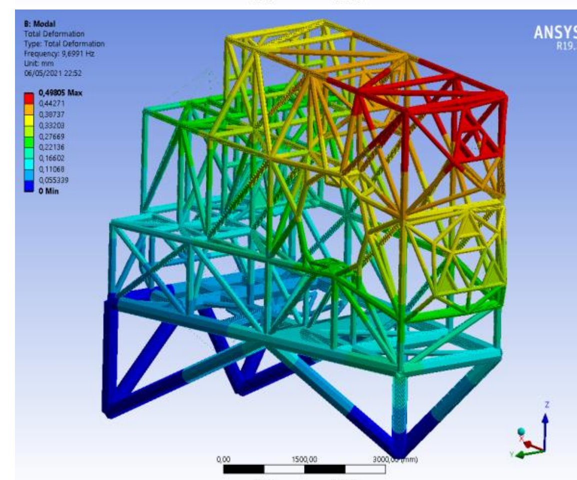
FE Model and Payloads applied to MSS_Type_6

Mass Budget installed on MSS (payloads)			
Element name	Net mass [kg]	Percentage of contingency	Gross mass [kg]
SP	130	20%	156
M6	178	20%	214
M7	305	20%	366
M8	334	20%	401
DM1/M9	586	11%	650
DM2/M10	998	9.5%	1092
M11	291	20%	350
DC	166	20%	
Holding structure DC+FM1	200	20%	715
FM1	230	20%	
LGSo	400	20%	480
FM3	70	20%	84
Linear stage fixed frame	180	10%	200
Linear stage cable chains	100	10%	110
Linear stage mobile frame	142	10%	
FM CU	213	20%	653
MCA	200	20%	
CTU	350	20%	420
LGS	600	20%	720
Enclosure MAORY	1600	20%	1920
Thermal tube MICADO side	40	20%	48
Electrical routing	270	20%	324
Glycol routing	80	20%	96
Thermal ricirculator system	25	100%	50
Total	7688	//	9049

8 T with 9 T of payload

FEA Results MAORY_MSS_Type_6 Static and Modal Analysis

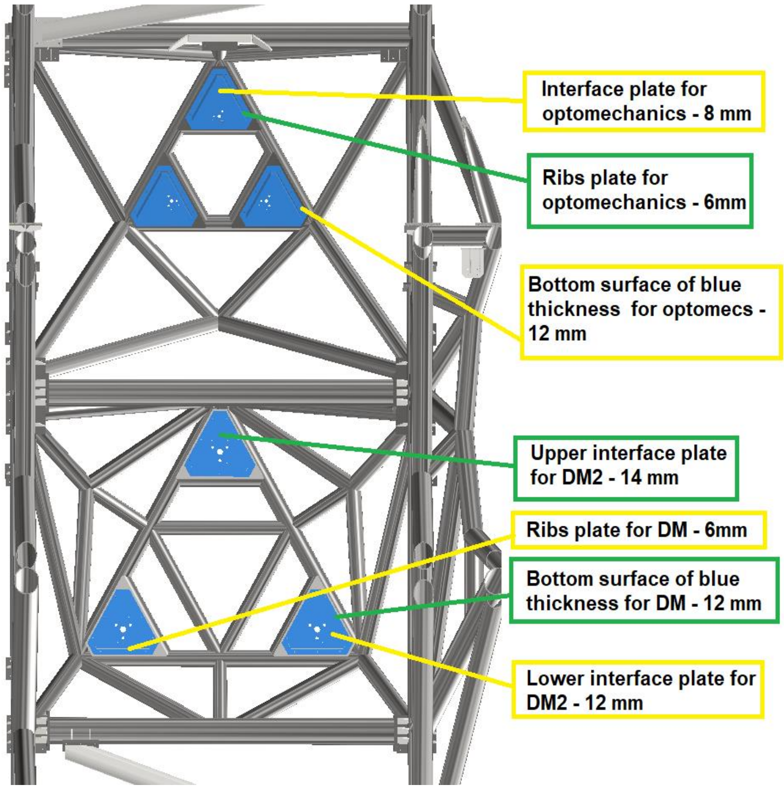


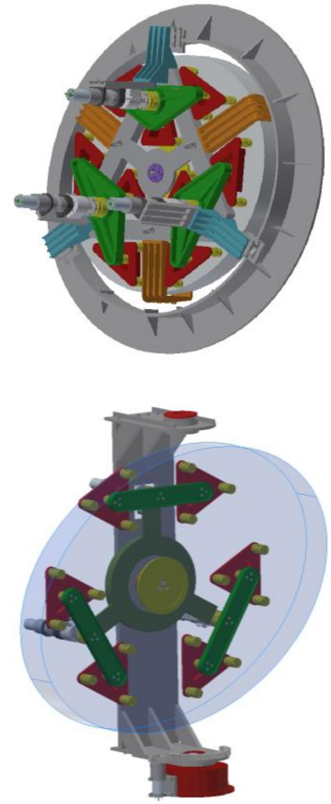


Mechanical Design & FEA

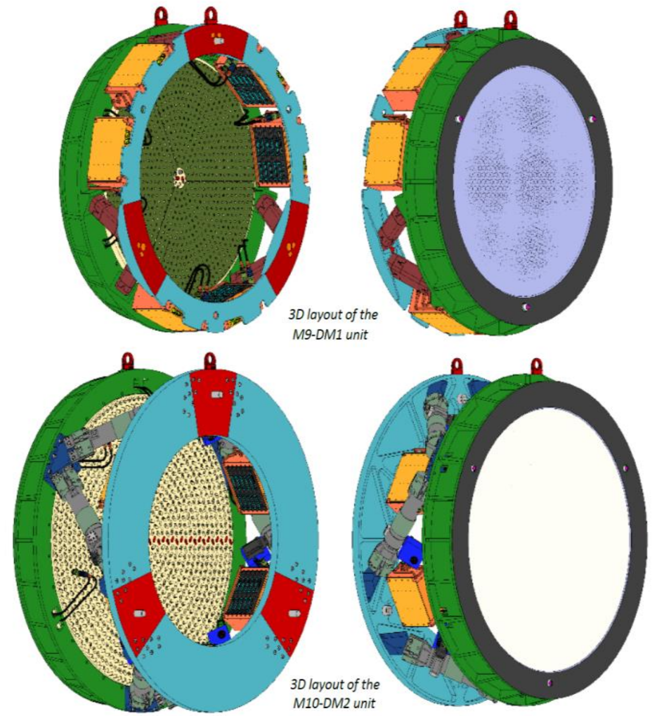
The road to the MAORY_2021 mechanical design

Upgraded interfaces also at CAD level, to better hosting both optomechanical elements and deformable mirrors





MAORY_M11_Flip mirror
Optomechanical element

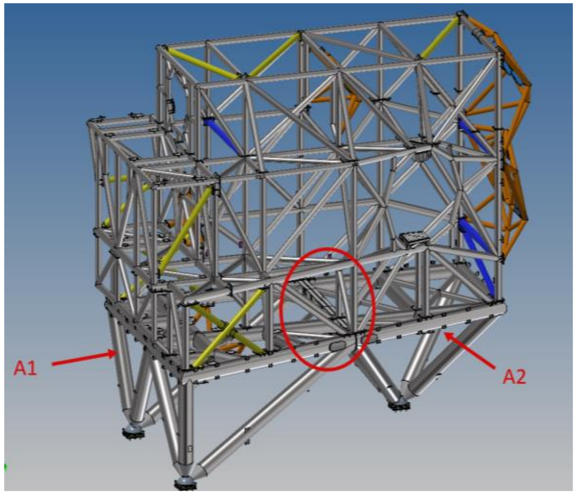


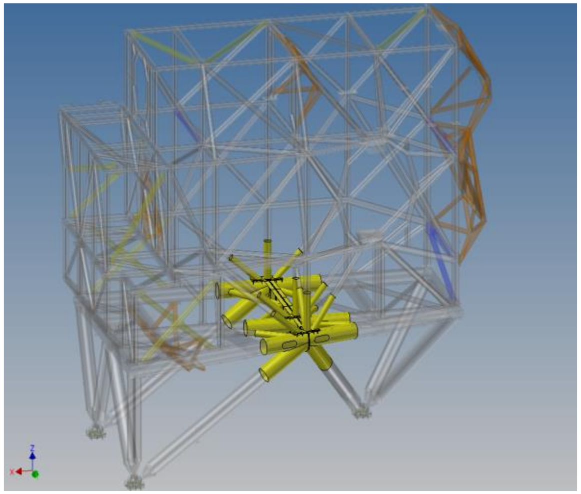
MAORY_M9-M10
Deformable mirror
Adaptive Optomechanical element

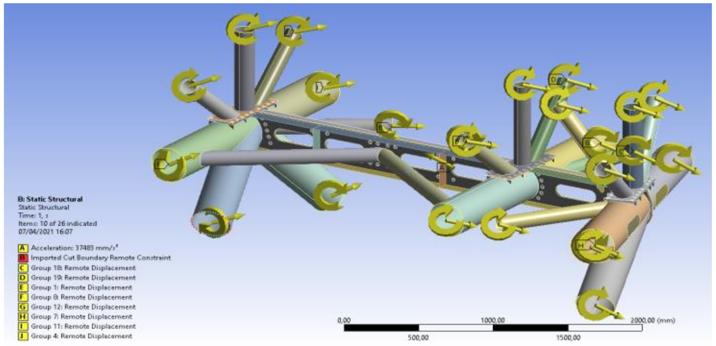
Mechanical Design & FEA

The road to the MAORY_2021 mechanical design

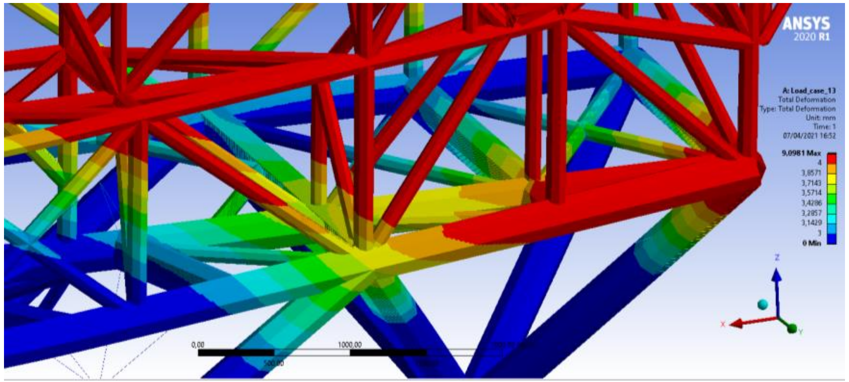
A full set of analyses was perform in order to verify the global behaviour of the MAORY MSS.
To have a better feedback also at local level e.g. critical joints, critical nodes with a large number of elements/beams that converge into them **…some local verifications with a submodeling FEA technique were also performed…**

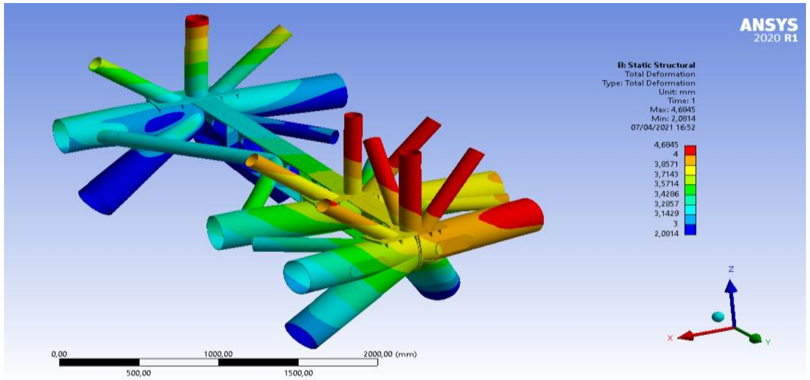






Remote displacements (boundary condition) of the sub-model



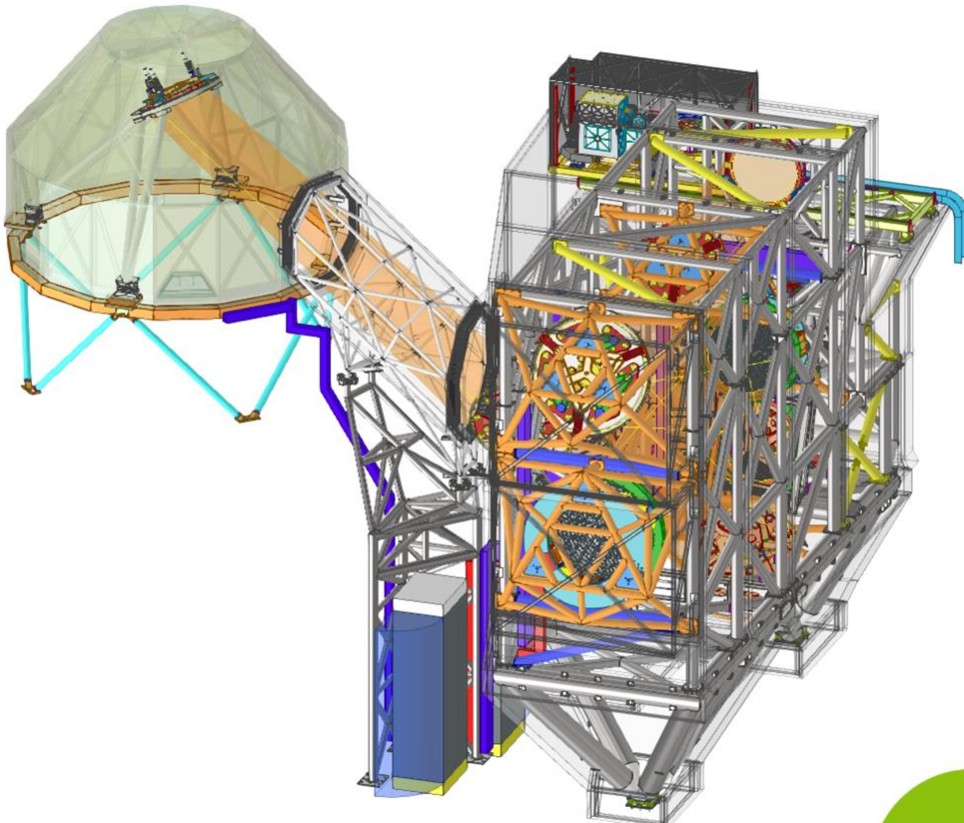


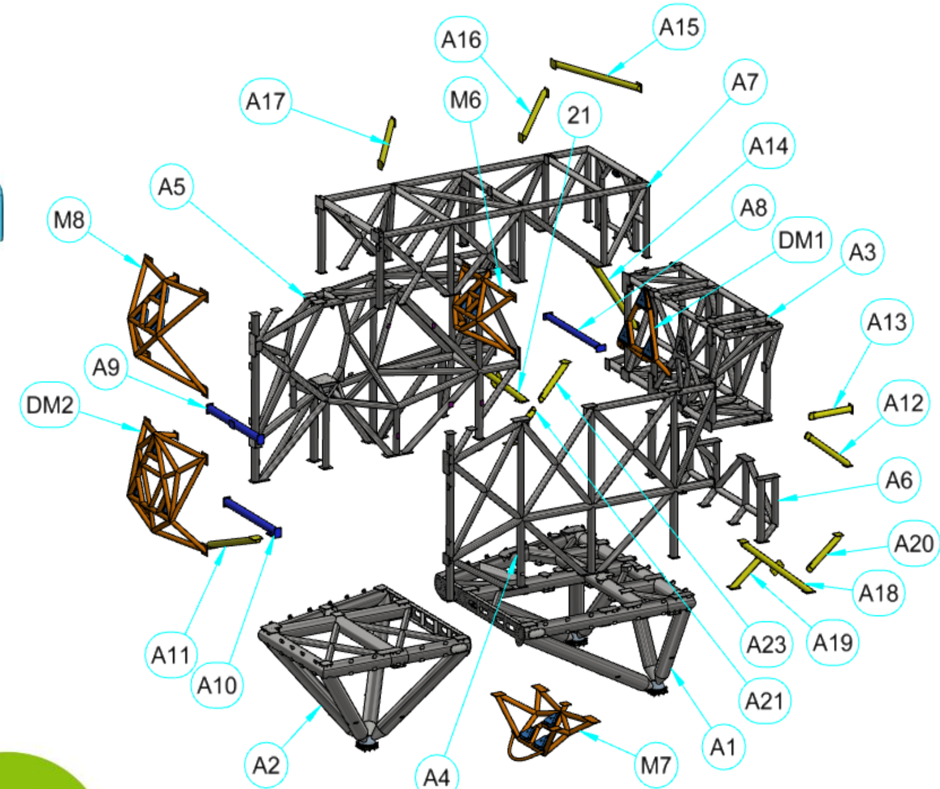
Comparison of maximum displacement between global and local FE model

Mechanical Design & FEA

The road to the MAORY_2021 mechanical design

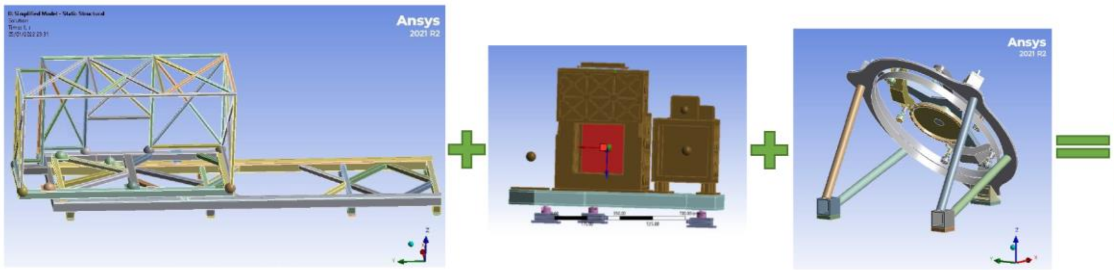
MAORY Mechanical Design of instrument presented at PDR. This Mechanical concept, designed and validated in **INAF-OACN**, under responsibility of **Vincenzo De Caprio**, was fully approved by ESO.

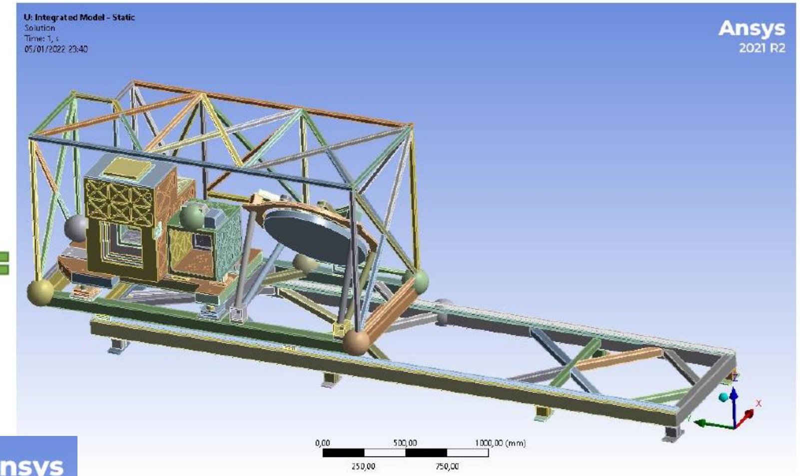


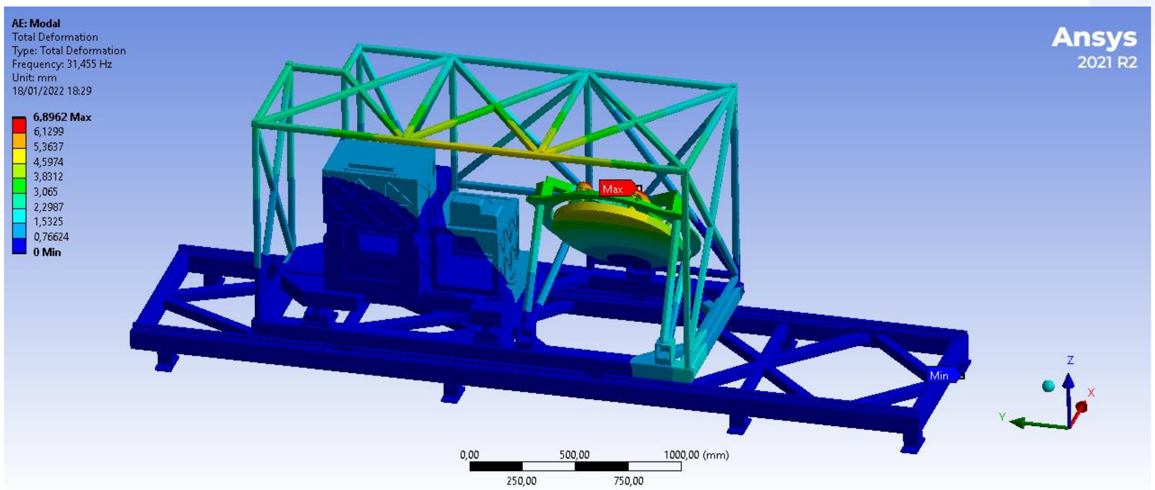


System level activities

The analysis of the **integrated model** allows us to say that the first eigenfrequency is bigger than the one required by technical specification







Tabular Data

	Mode	Frequency [Hz]
1	1,	31,695
2	2,	35,628
3	3,	39,785
4	4,	39,964

Tabular Data

	Mode	Frequency [Hz]
1	1,	31,455
2	2,	35,453
3	3,	36,234
4	4,	37,936

Tabular Data

	Mode	Frequency [Hz]
1	1,	31,618
2	2,	35,648
3	3,	39,548
4	4,	39,79

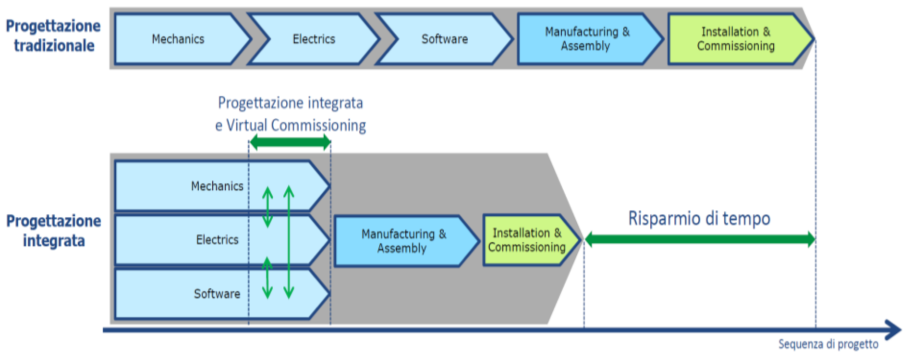
The first eigenfrequency is not a whole structure mode, but involve just in a small participant mass localized in the bracket of the FMCU. Anyway, the minimum value of the eigenfrequency mode is around 31.45 Hz for the Position_2.

Due to the so high 1st eigenfrequency of the CU Selector integrated model, no particular attention has to be paid about the modal analysis, i.e. the model behaves better than what the requirements asks. In fact:

fmin (31.45 Hz) > fmin_REQ (21 Hz)

Integrated Design

Integrated Design is the result of a collaborative approach by a multidisciplinary team of specialists with common objectives. Passionate experts enthusiastically undertake, even the most complex challenges, synergistically and creatively contributing to the enhancement of each project.



- Increase and improve the quality of interactions
- Optimize day-to-day collaboration among the members of the team for electromechanical design.
- Save a lot of time in the design phase
- Issues are identified in early design phases: all the team is involved
- Better traceability of the design steps through Product Data Management tool (PDM).

INAF Mini-Grant Cianniello

Richiesta: Un approccio integrato alla progettazione meccanica per strumentazione astronomica da terra: dal concetto alla prototipazione rapida 3D, attraverso metodi di trade-off ed analisi FE FINAL

Richiesta collegata alle seguenti Schede

Titolo Scheda	Acronimo	Coordinatore	Azione
MAORY, the Adaptive Optics Module for ELT	MAO	paolo.ciliegi	Visualizza Scheda

Proposer CV

File allegato: CVfile Curriculum Vitae - Cianniello Vincenzo.pdf

General Info

Request Title

Un approccio integrato alla progettazione meccanica per strumentazione astronomica da terra: dal concetto alla prototipazione rapida 3D, attraverso metodi di trade-off ed analisi FE

Type of Grant	Primary RSN	Request Author's Name and Email
Mini Grant	RSN5	vincenzo.cianniello vincenzo.cianniello@inaf.it

Declaration that the activities covered by the present request do not have any funding already available

True

Declaration that the proposed project satisfies the requirements described in the INAF Call

True

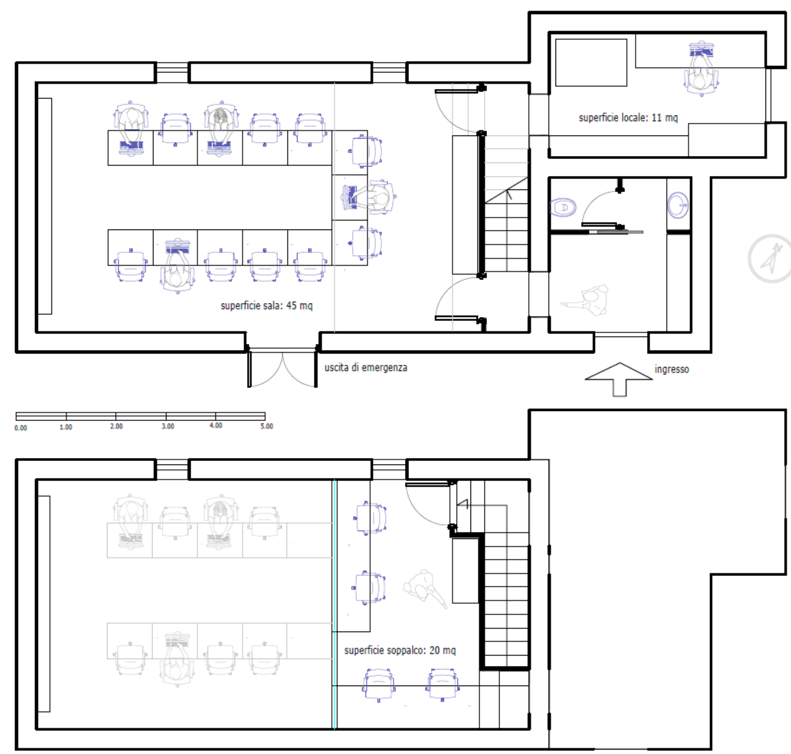
Short Abstract

La realizzazione di strumentazione astronomica per telescopi di classe ELT ci pone al cospetto di una delle più entusiasmanti sfide tecnologiche degli ultimi tempi. Tale compito, dal punto di vista ingegneristico, merita senz'altro un approccio integrato ed innovativo al fine di supportare e stimolare l'attività di tutto il team di ricerca coinvolto.
Tale proposta di ricerca vuole approfondire, acquisendo ulteriore know-how, aspetti peculiari della progettazione meccanica avanzata di uno strumento come MAORY. I mezzi essenziali da sfruttare in un contesto di ingegneria concorrente, per passare dallo sviluppo dell'idea alla finalizzazione del design in tempi brevi e con una qualità molto elevata, sono: CAD parametrizzabili, Finite Element Analyses, trade-off e prototipazione rapida 3D.

Concurrent design facility

This **CDF** allows a coordinated and multidisciplinary effort in the design phase, during the feasibility study and the preliminary design phase. Concurrent design main facility in Naples as part of **STILES** proposal in the **PNRR** contest.

Modular approach
- Two other CDF nodes in Brera and Medicina
- New nodes in other INAF Institutes potentially realized in the future



Design of the proposed **CDF** – exterior (left) and Internal layout (right)

INAF
OSSERVATORIO ASTRONOMICO
DI CAPODIMONTE

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GENIUS
W E S O L V E P R O B L E M S

GRAZIE

VINCENZO.CIANNIELLO@INAF.IT

RSN 5 - INAF

Bologna, 22-24 giugno 2022