

Overview and update of ESO ELT Construction Project



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ESO ELT Programme Manager

NSF Workshop – March 2024





ESO in a nutshell

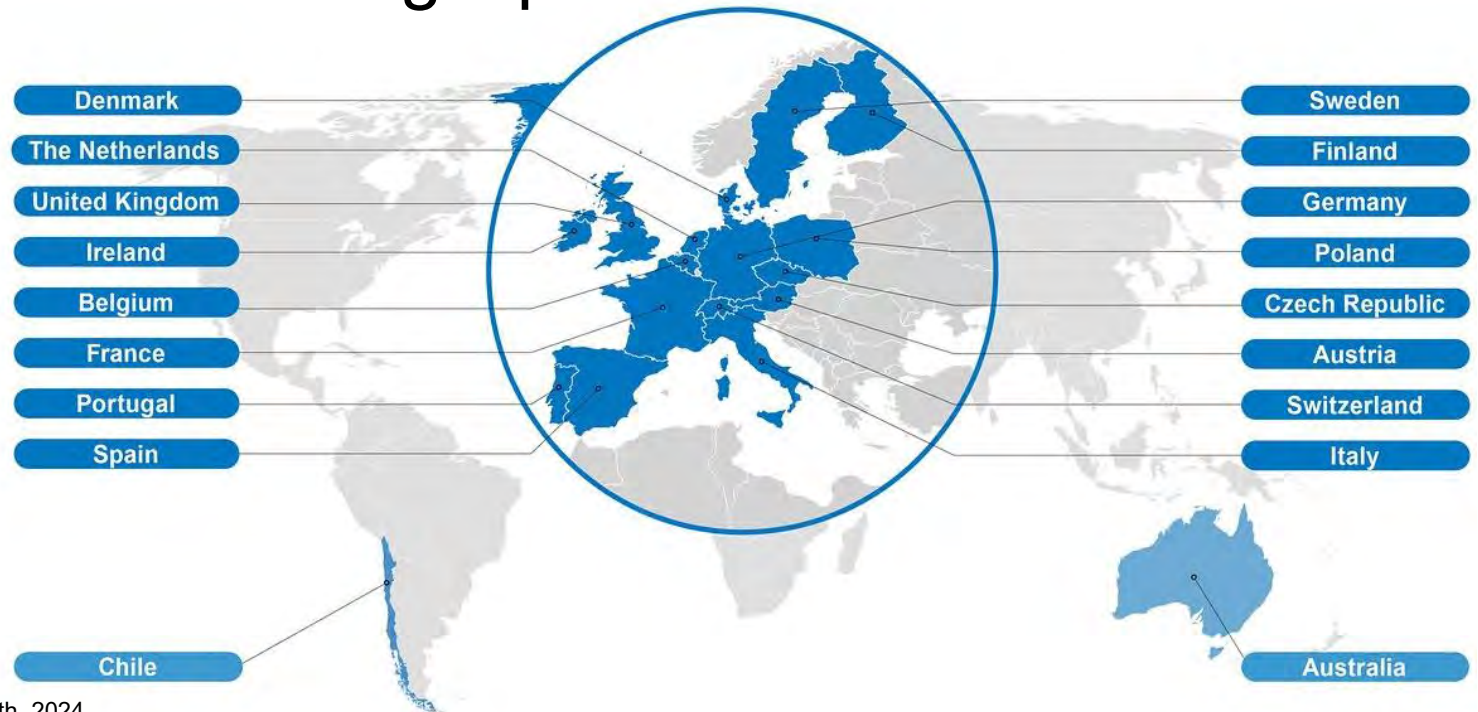
European Southern Observatory

What is ESO?

- ESO – European Southern Observatory
- Intergovernmental Organisation
- Set up 60 years ago by 6 Countries
- Currently 16 Countries + AU as strategic partner

- ESO's Mission:

- Build and operate world-class ground-based astronomical facilities
- Foster collaboration in Astronomy



2023 Budget

- 240 MEUR Income Budget
 - MS contributions plus third party income
 - 96 MEUR are personnel costs
- Annual contributions from the Member States
 - Proportional to NNI
- DE 22%, UK 16%, FR 15%, IT 11%

ESO multiple programmes

- Visual/infrared light
 - La Silla telescopes
 - VLT, VLTI, VISTA and VST on Paranal
 - ELT to come, on Armazones
- Submillimeter radio waves
 - APEX, ALMA at Chajnantor, in partnership
- Gamma-rays
 - Cherenkov Telescope Array near Paranal, to come



ESO Sites + HQ in Garching bei Muenchen, DE



Chajnantor - ALMA and APEX
(Submillimeter radio waves)
 5.100m

Paranal – VLT/ VLTI, ELT and CTA
(Visual/infrared light and Gamma-rays)
 2.640m and 3.046m

La Silla – 3.6m, NTT and hosted telescopes
(Visual/infrared light)
 2.400m

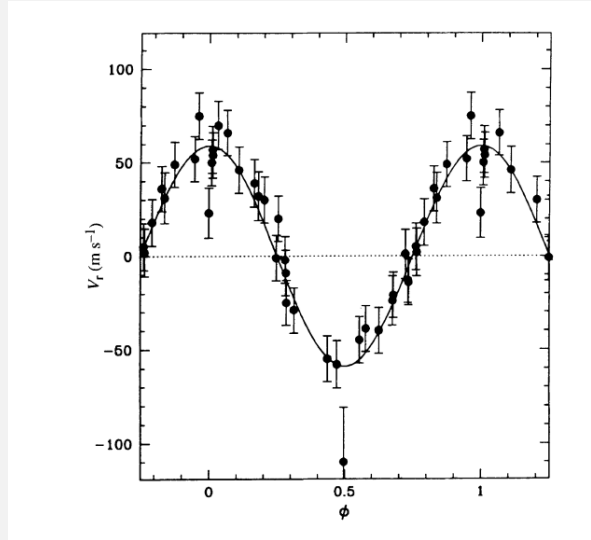
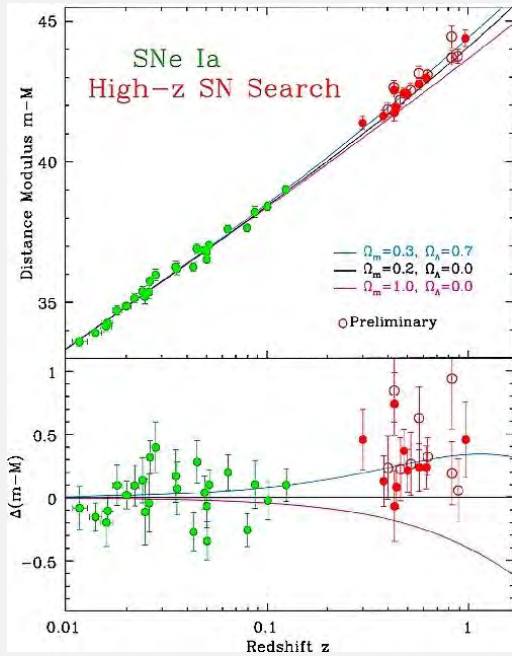
Santiago
 ESO offices and JAO

The Paranal model (VLT / ELT)

- ESO builds the telescopes and all the infrastructure
- Instruments are developed in partnership with consortia
 - ESO provides capital costs, oversight, support and some critical items
 - Effort from consortia compensated by GTO (Guaranteed-Time Observ.)
- ESO operates the entire facility
 - Technical downtime < 3%

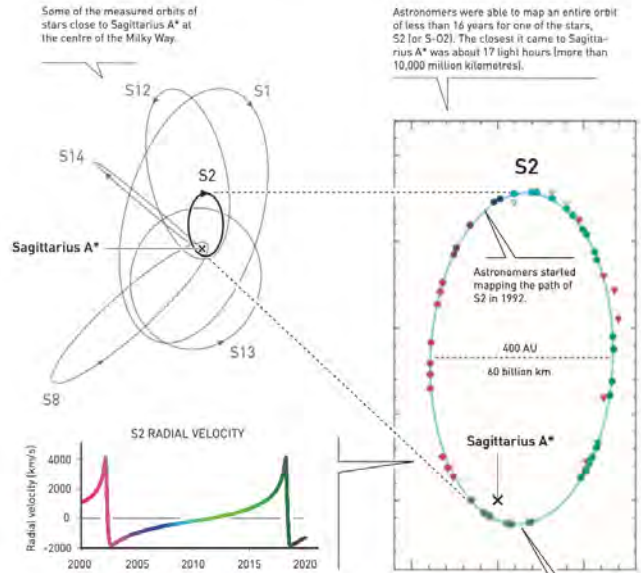


Ground based OIR astronomy is at the forefront of physics (three Nobel prizes in the last 15 years)



Stars closest to the centre of the Milky Way

The stars' orbits are the most convincing evidence yet that a supermassive black hole is hiding in Sagittarius A*. This black hole is estimated to weigh about 4 million solar masses, squeezed into a region no bigger than our solar system.



The S2 star's radial velocity increases as it approaches Sagittarius A* and decreases as it moves away along its elliptical orbit. Radial velocity is the component of the star's velocity that is in our line of sight.

Closest to Sagittarius A* in 2002 and 2018, S2 reaches its maximum velocity of 7 600 km/s.

The Nobel Prize in Physics 2011



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The Nobel Prize in Physics 2019



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The Nobel Prize in Physics 2020



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The Extremely Large Telescope

ELT in a Nutshell



Why mirror diameter matter

Hubble Space
Telescope (2,5m)



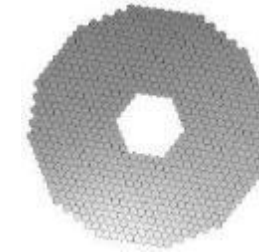
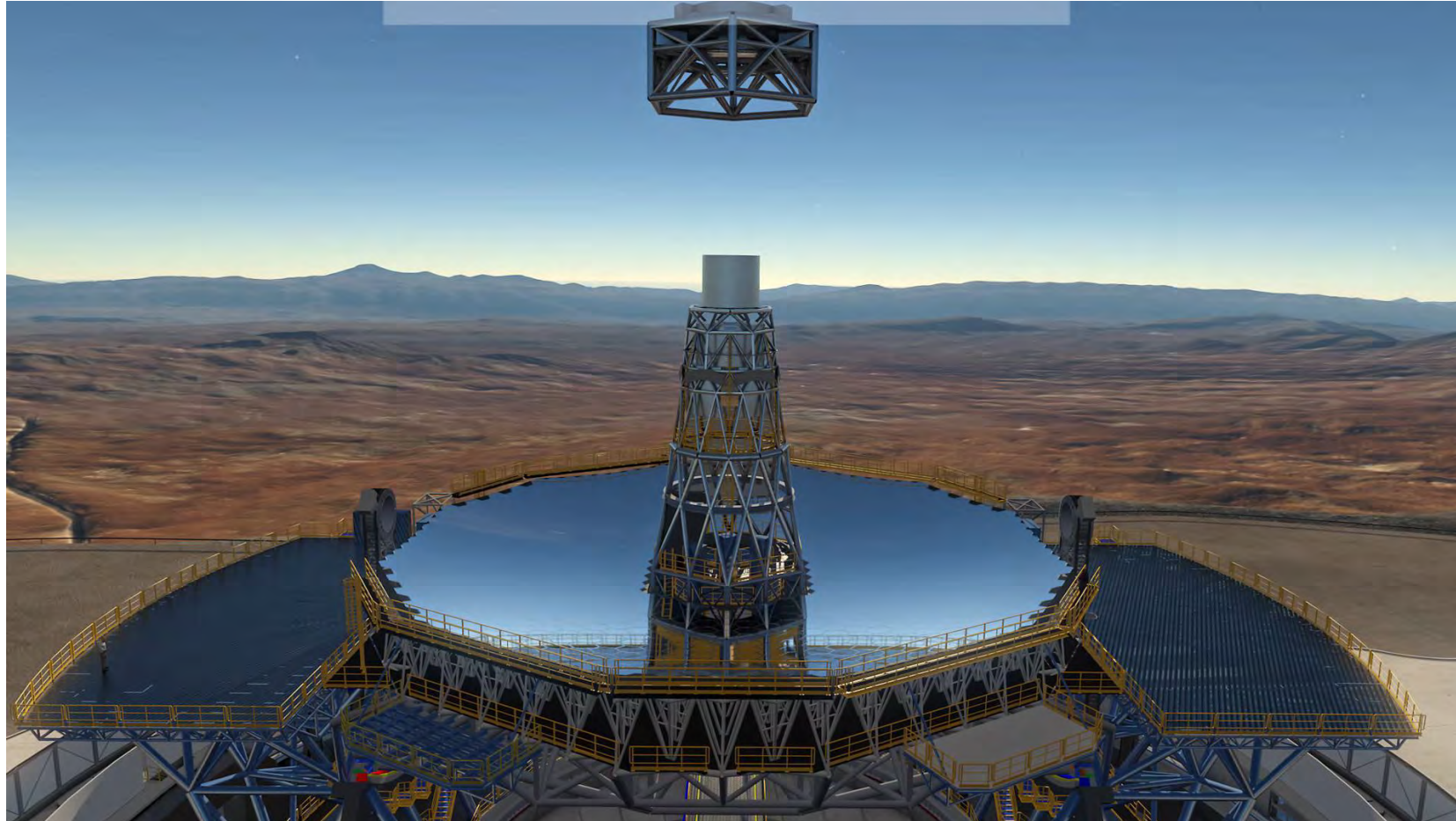
James Webb Space
Telescope (6.5m)



ELT (39m)



Light path through the biggest eye on sky



M1 Unit
39-m
Concave – Aspheric f/0.9
Segmented (798 Segments)
Active + Segment shape Control



M2 Unit
4-m
Convex Aspheric f/1.1
Passive + Position Control



M3 Unit
4-m – Concave – Aspheric f/2.6
Active + Position Control



M4 Unit
2.4-m
Flat
Segmented (6 petals)
Adaptive + Position Control



M5 Unit
2.7x2.1-m
Flat
Passive + Fast Tip/Tilt

Funding History: a bumpy but successful journey

2006: Green Light for **ELT detailed Studies** (PR [eso0646](#))

2012: **ESO Council approves** ELT programme (PR [eso1225](#)) for a cost of 1083 M€ (2012 EC)

- However, large expenditure (contracts) **contingent** on confirmation by some ESO Member States and joining of Brazil as new member state to reach the 90% funding target established in 2011
- Exceptions: *Site preparation (access road & platform)* & *M4 adaptive mirror design* contracts started

2014: **Green Light** for E-ELT **Construction** (PR [eso1440](#)) but in two phases to respect the 90% funding target

- 90% of Phase 1 available despite Brazil not joining

2017 – 2020: **gradual incorporation** of “Phase 2 items” into the approved scope and budget:

- M1 five inner rings and 7th sector (2017), LTAO for HARMONI (2018), electrical power conditioning system (2019), 2nd Pre-Focal Station, +2 Laser Guide Star units and atmospheric monitoring (2020)

2020: **ELT Total Cost Exercise** ([ann20034](#)) raising the Cost-at-Completion by 10% to **1.3 b€** (2020 EC) to replenish contingency and include all remaining Phase 2 items as well as ELT-related cost at ESO Organization level (e.g. new Integrated Operation Programme, new ERP, etc.)

→ A small-steps approach but with strong and sustained commitment from ESO Members States (Council) and the European astronomical community

ELT Industrial Partners and Instruments Institutes





Contracts status progress
95-100%
50-95%
<50%

Closed or under warranty

January '24

ELT Project	Description of Work	Contract Signature Date	Contractor	Status	Design	Manuf.	Integration
PJ42.01 Project Office	PA Consultancy Services	Jan-16	ISQ	On-going	N/A	N/A	N/A
PJ42.01 Project Office	ISVW Consultancy Services	Jan-16	Critical Software	On-going	N/A	N/A	N/A
PJ42.01 Project Office	Construction All Risks Insurance	Mar-18	SCOR	On-going	N/A	N/A	N/A
PJ42.01 Project Office	Freight Forwarding Services	Oct-20	DSV	On-going	N/A	N/A	N/A
PJ42.02 DMS	Consultancy Support	Jun-13	Ramboll	On-going	N/A	N/A	N/A
PJ42.02 DMS	Consultancy Support - On site activities	May-23	CyD	On-going	N/A	N/A	N/A
PJ42.02 DMS	DM&S Design and Construction Contract	May-16	ACe Consortium	On-going	100%	95%	40%
PJ42.03 Optomechanics	M4 Phase 1 Preliminary Design	May-12	AdOptica	Closed	100%	100%	100%
PJ42.03 Optomechanics	M4 Unit Final Design and Manufacturing	Jun-15	AdOptica	On-going	100%	95%	85%
PJ42.03 Optomechanics	M1 Segment Supports - Qual. Units	Jan-15	VDL	Closed	100%	100%	100%
PJ42.03 Optomechanics	M1 Segment supports - Qual. Units	Feb-15	CESA	Closed	100%	100%	100%
PJ42.03 Optomechanics	M4 Mirror Shells Supply	Jul-15	Safran Reosc	Under warranty	100%	100%	N/A
PJ42.03 Optomechanics	M2 Mirror and Auxiliary Equipment Supply	Jul-16	Safran Reosc	On-going	100%	85%	N/A
PJ42.03 Optomechanics	M2 Blank Supply	Jan-17	Schott	Closed	100%	100%	100%
PJ42.03 Optomechanics	M3 Blank Supply	Jan-17	Schott	Closed	100%	100%	100%
PJ42.03 Optomechanics	M3 Mirror and Auxiliary Equipment Supply	Feb-17	Safran Reosc	On-going	100%	38%	N/A
PJ42.03 Optomechanics	M2 and M3 Cell Design and Manufacturing	Jan-17	Sener	On-going	95%	87%	77%
PJ42.03 Optomechanics	M1 Edge Sensors Design and Manufacturing	Jan-17	FAMES	On-going	100%	56%	N/A
PJ42.03 Optomechanics	M1 Mirrors Polishing	May-17	Safran Reosc	On-going	100%	42%	6%
PJ42.03 Optomechanics	M1 Blanks Supply	May-17	Schott	On-going	100%	81%	N/A
PJ42.03 Optomechanics	M1 Position Actuators	Jun-17	PI	On-going	100%	42%	28%
PJ42.03 Optomechanics	M1 Segment supports - Production	Apr-18	VDL	On-going	100%	82%	NA
PJ42.03 Optomechanics	M5 Blank Supply + Polishing	Mar-19	Safran Reosc	On-going	100%	55%	10%
PJ42.03 Optomechanics	M5 Cell Design and Manufacturing	Nov-19	Sener	On-going	100%	85%	45%
PJ42.03 Optomechanics	M1 Segment Assemblies Manipulator	Jan-21	Sener	On-going	100%	25%	0%
PJ42.03 Optomechanics	M1 Segment Assemblies Local Coherencer	May-21	IDOM	On-going	90%	0%	0%
PJ42.04 Control	Core Integration Infrastructure	Jul-17	Cosylab AB	Closed	100%	100%	100%
PJ42.04 Control	M1LCS Cabinets Procurement and AIV	Dec-20	PROCON	Under warranty	100%	100%	100%
PJ42.04 Control	M1LCS Cabinets Heat Exchangers	Nov-20	AAVID Thermalloy	Under warranty	100%	100%	100%
PJ42.04 Control	CSW Outsourcing Contract	Mar-23	N7 SPACE Sp. z o.o.	On-going	N/A	N/A	N/A
PJ42.05 Civil Infrastructure	Road and Platform	Dec-13	ICAFAL	Closed	100%	100%	100%
PJ42.05 Civil Infrastructure	Paranal ELT Technical Facility Design and Construction	Mar-18	Abengoa	Closed	100%	100%	100%
PJ42.06 Support Infrastructure	supply and installation of ABC Power substations (230kV + 0.4	Oct-16	SIEMENS	Closed	100%	100%	100%
PJ42.06 Support Infrastructure	M1 Coating Plants Supply	Jun-18	AGC	Under warranty	100%	100%	100%
PJ42.06 Support Infrastructure	Large Mirrors Coating Plant Supply	May-21	AGC	On-going	100%	55%	0%
PJ42.06 Support Infrastructure	M1 Mirror Washing & Stripping plant Supply	Jan-20	Fagerström Industriekonsult	On-going	100%	35%	0%
PJ42.06 Support Infrastructure	Power Conditioning System	Nov-19	SAESA	On-going	N/A	N/A	N/A
PJ42.06 Support Infrastructure	ELT LN2 Infrastructure	Nov-23	AS Scientific Products Ltd.	On-going	5%	0%	0%
PJ42.09 Science Data Ops	Dataflow Software Components for ELT	Nov-18	Etamax	On-going	N/A	N/A	N/A
PJ18.10 Instrumentation	MICADO Construction	Oct-15	MPE	On-going	95%	25%	0%
PJ18.10 Instrumentation	HARMONI Construction	Oct-15	STFC	On-going	70%	0%	0%
PJ18.10 Instrumentation	METIS Construction	Oct-15	NOVA	On-going	100%	25%	0%
PJ18.10 Instrumentation	MAORY Construction	Feb-16	INAF	On-going	70%	0%	0%
PJ18.10 Instrumentation	IR Detectors for HARMONI, MICADO, METIS	Jul-18	Teledyne	On-going	100%	80%	N/A
PJ18.10 Instrumentation	C-RED Cameras for MAORY	Jul-18	FLI	Under warranty	100%	100%	100%
PJ18.10 Instrumentation	CCD-zz9 detectors for MAORY, MICADO, HARMONI, PFS-A, METIS	May-19	Teledyne	Under warranty	100%	100%	100%
PJ18.10 Instrumentation	MUSE type detectors	Sep-19	Teledyne	Under warranty	100%	100%	N/A
PJ18.10 Instrumentation	AOWFS Cameras Production	Dec-22	TAS-E	On-going	22%	0%	0%
PJ42.11 Optical Control	PFS-A Main system Design and Manufacture	Apr-18	IDOM	On-going	100%	95%	75%
PJ42.11 Optical Control	Laser Sources	Dec-17	Toptica	On-going	100%	100%	83%
PJ42.11 Optical Control	Laser Projection Subunits	Dec-20	TNO	On-going	100%	45%	0%
PJ42.11 Optical Control	PDS Powered Optics	Feb-23	Bertin	On-going	50%	0%	0%
PJ42.11 Optical Control	Laser Trackers	Oct-21	Hexagon Wetzar	On-going	N/A	70%	NA



DMS Status

DMS (by ACe, IT) Overall progress

	Progress in %
Dome manufacturing (in Europe)	~90
Main Structure manufacturing (in Europe)	~75
Dome foundations progress on site	100
Main Structure foundations progress on site	100
Dome assembly global progress on site	~75
Main Structure assembly global progress on site	~2
Overall (total) estimated progress	~75

ELT Construction 2019 - 2023

2019-07-09



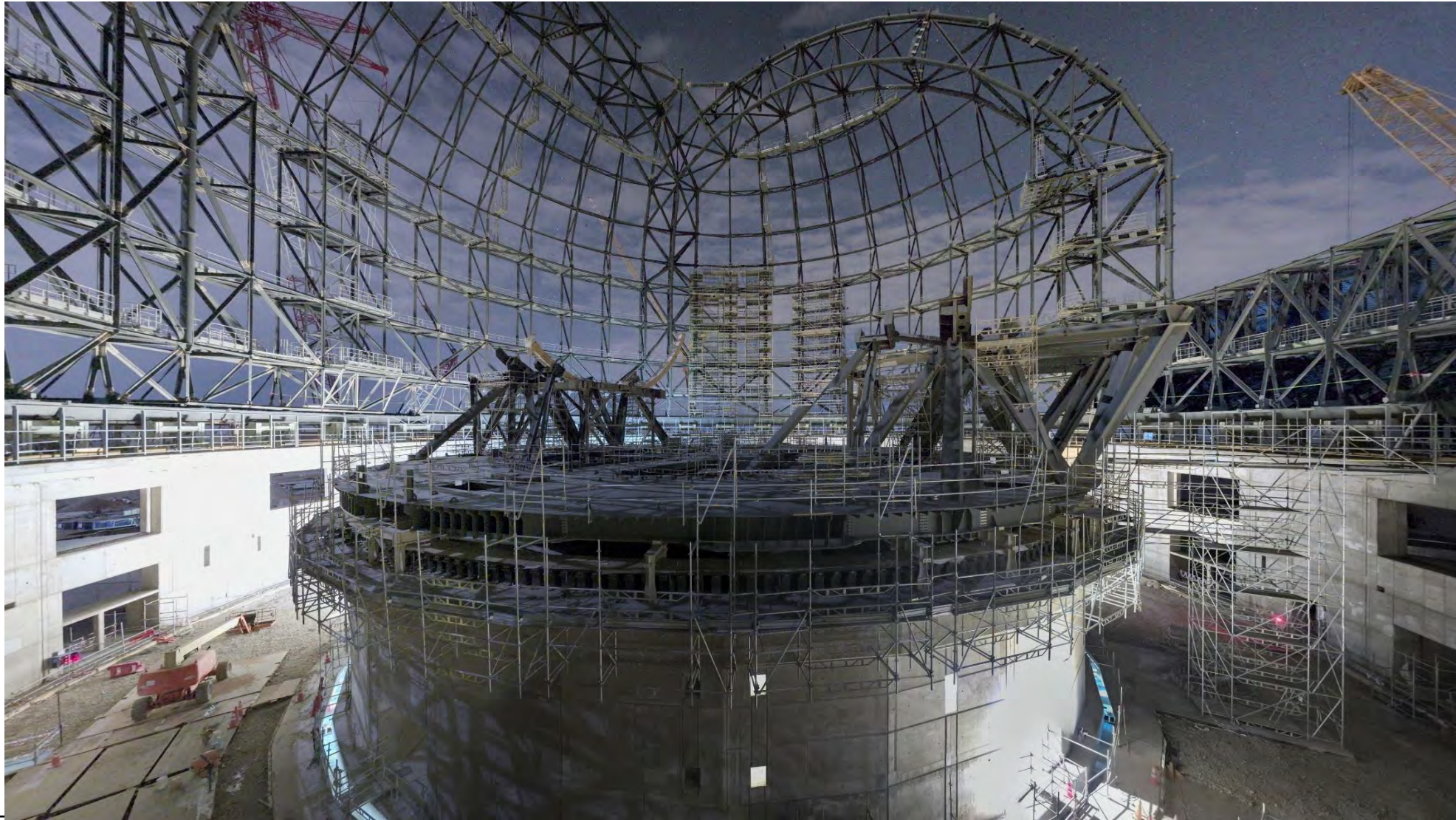
Eppur si muove! - 16 January 2024



Status 3rd March 2024 – Cladding & Roof



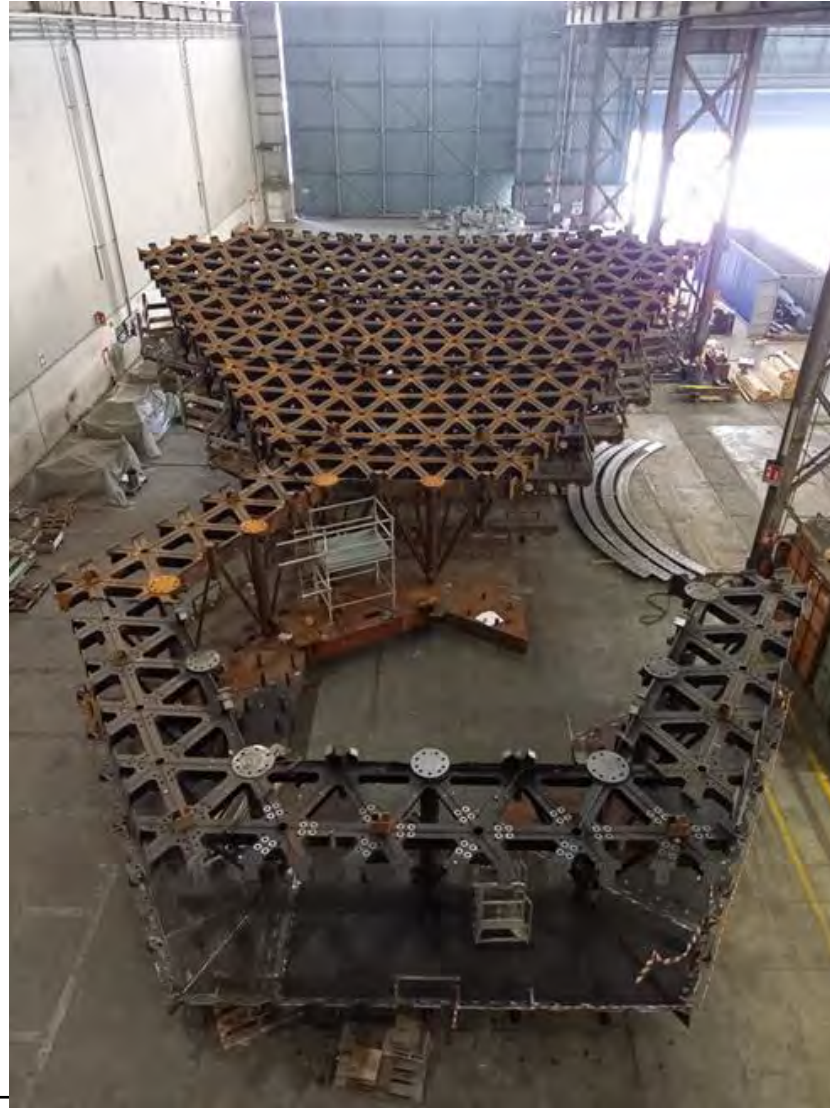
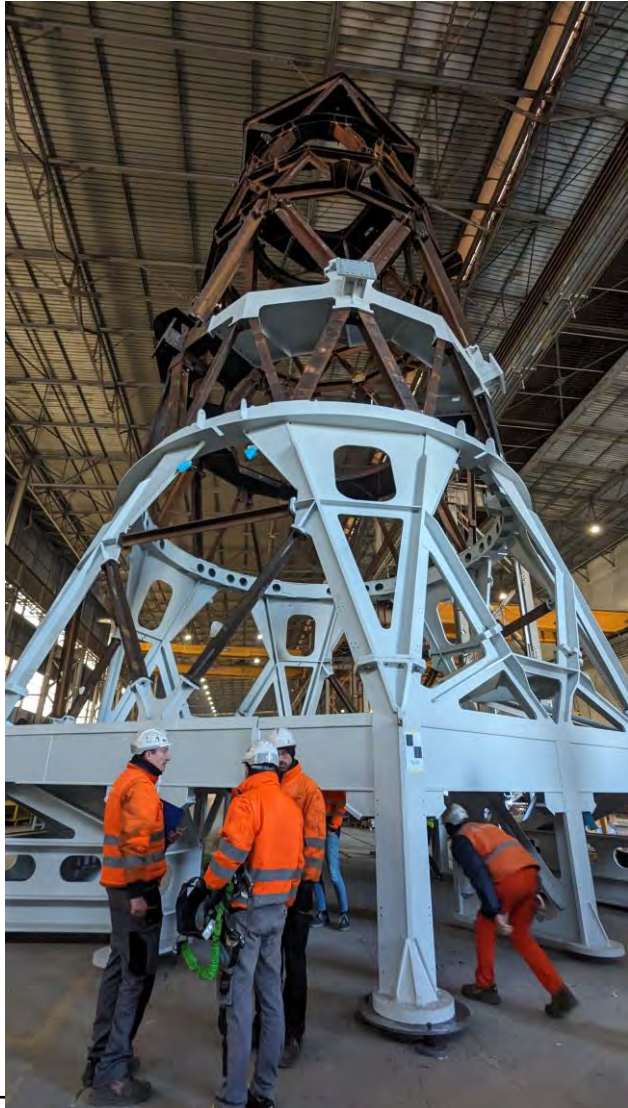
Status 4th March 2024 – Nasmyth Platform Support Beams & Alt lateral Tracks being installed



Telescope Structure Anti-seismic devices

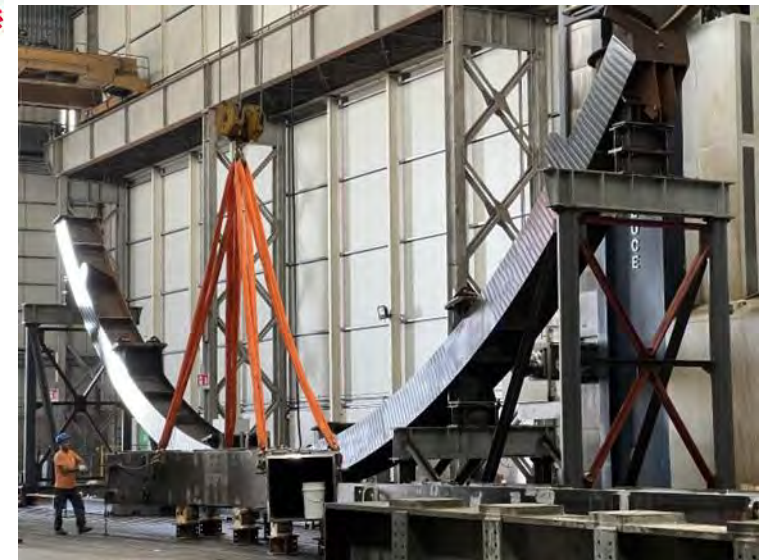


Main Structure Manufacturing in Europe



CIMOLAI

webuild



Status 4th March 2024



Data Classification: Public



Optomechanics Status

M1 Unit

931 x M1 Segments

931 x Blanks + 19 x Spare Blanks
931 x Segments Polishing

4566 x M1 Edge Sensors

4566 x Sensors + 805 x Electronics + Spares

931 x M1 Segment Supports

& SA Auxiliary Equipment

[SA Handling Tools, SA Transport Containers, SA AIV Tools]

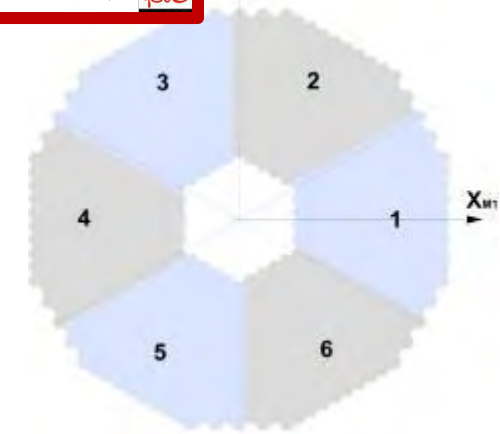
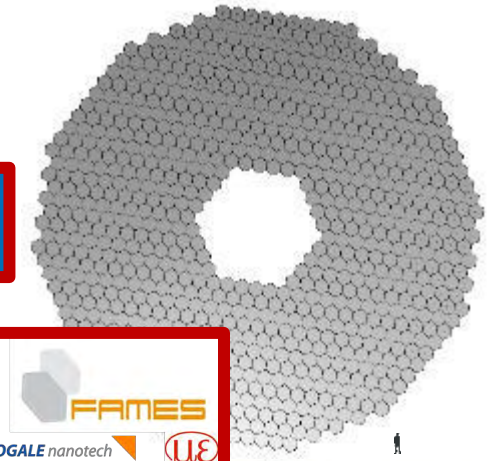
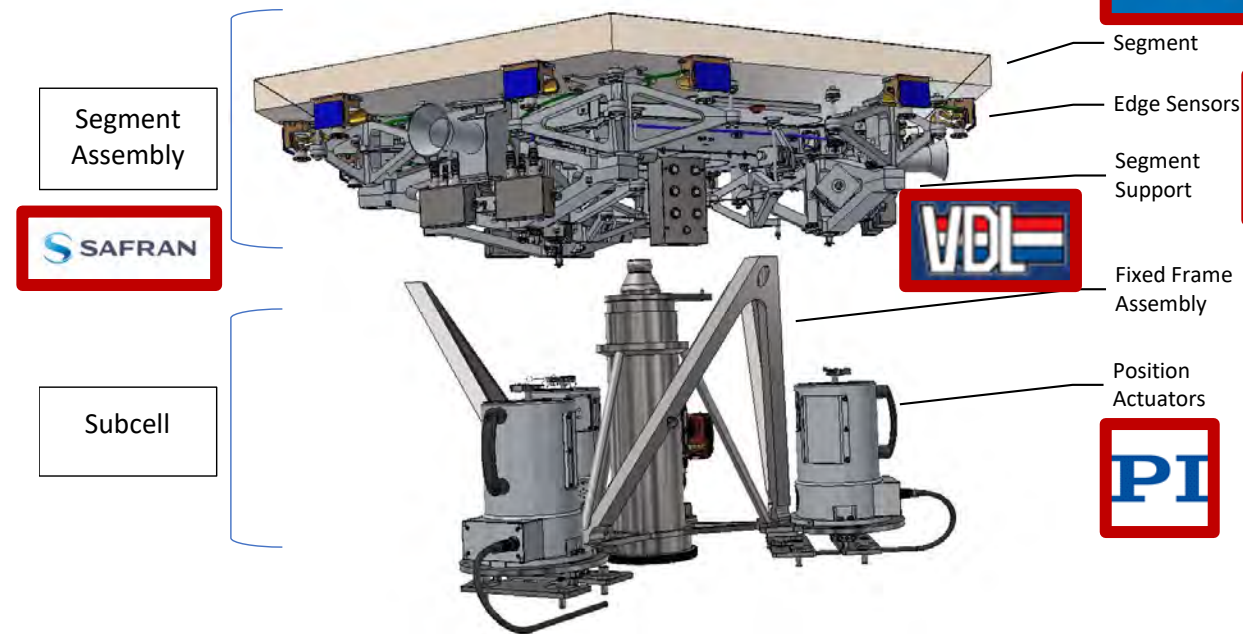
2418 x M1 Position Actuators

2394 x Actuators + 806 x Control Modules + Spares

M1 Auxiliary Equipment

Aux. Sensors, Mass Dummies. Carts, Stands, Manipulator, Phasing Gun, Alignment Tools

39-m diameter
6 x 133 segments (1.4-m)
1 x 133 spare segments
Total: 931 segments



Including glass, mechanics, electronics:
⇒ more than 10 000 components

M1 Mirror		
Outer diameter (mm)		39146.0
Inner diameter (mm)		9418.4
M1 Optical Prescription		
Radius of curvature (mm)		68685
Conic constant		-0.996473

Data Classification: Public

M1 Segment Blanks and Supports

M1 segment **blanks** (Zerodur®) produced by SHOTT (DE)

- Total: 949
- **Accepted: 873 (~92%);** Delivered 603 (64%)



M1 segment **supports** produced by VDL (NL)

- Total: 936
- **Accepted: 806 (~86%);** Delivered 590 (63%)



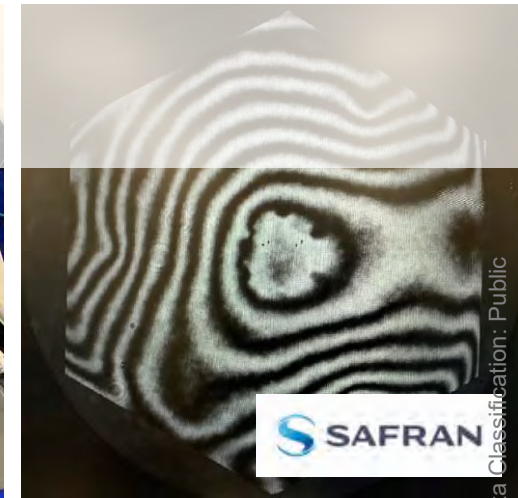
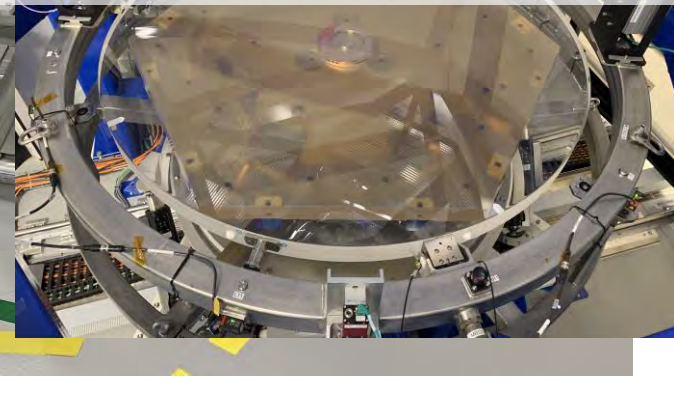
All **fixed frames** (840) delivered to Chile

- Will be installed by ACe (DMS)



M1 Polishing at Safran Reosc

- **Production rate** around 4 M1SA/week with a goal of 5/w expected soon
- **100th M1 Segment Assemblies (M1SA) finished** on 1st Nov
- As of 23 Feb 2024: **142 M1SA finished and packed**
- **66 more in various stages of manufacturing**
- **First 18 M1SA accepted & shipped** in Dec'23
- **Two more batches (54 M1SA) shipped** Feb'24



M1 Segment Assemblies Manufacturing Status - 23/02/24

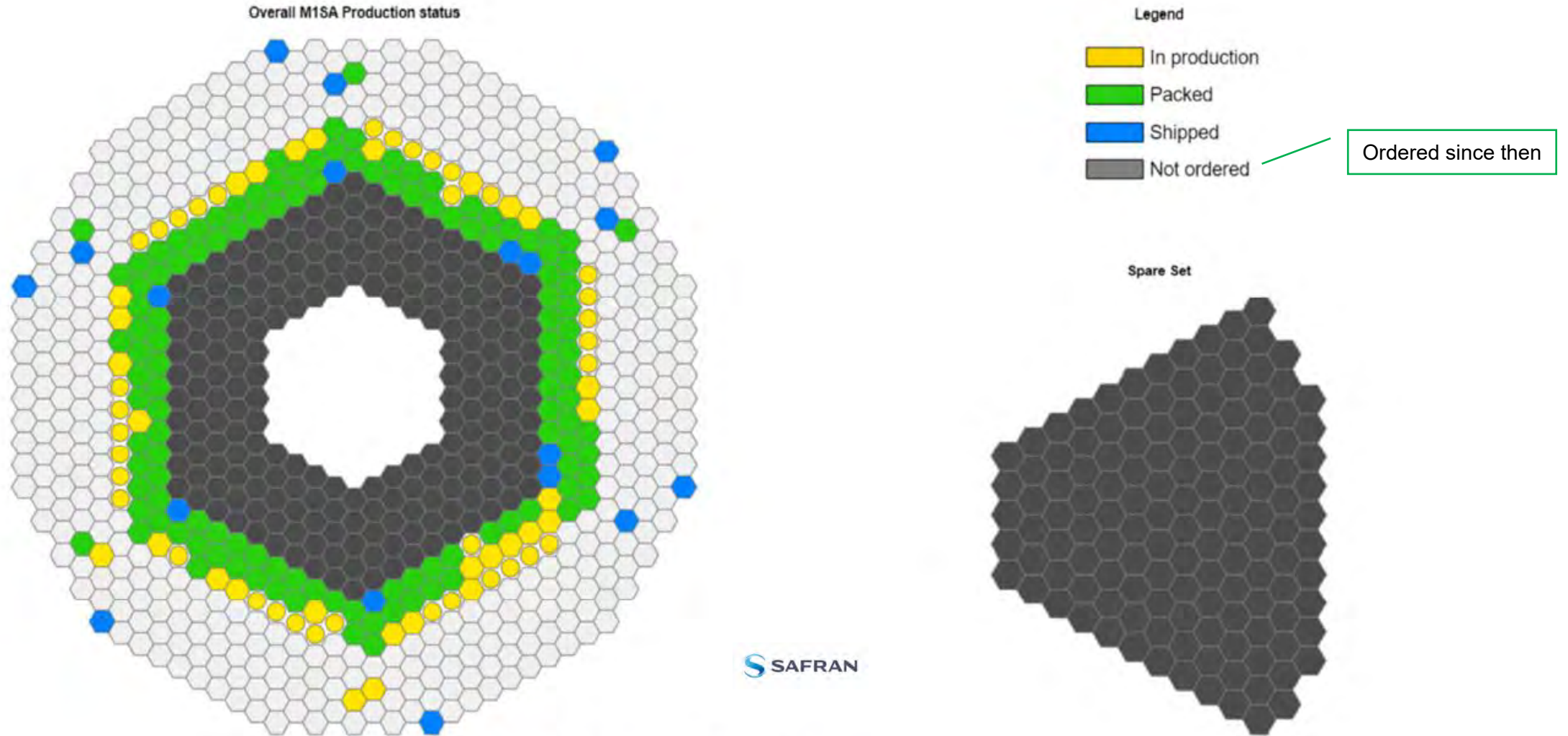


Figure 4: overall progress of the manufacturing

The first 18 M1 Segment Assemblies delivered to site



Lined up for delivery inspection at Safran Reosc – 16/11/2023



Packing in refrigerated container – 7/12/2023



Arriving at Paranal – 12/01/2024

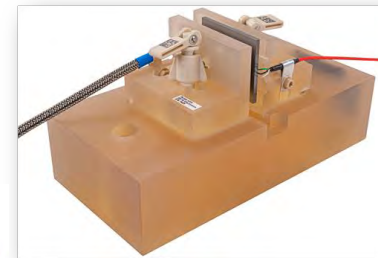
M1 Position Actuators (PACTs) & Edge Sensors

M1 PACTs developed by Physik Instrumente - PI (DE)

- 5 batches (51%) in ESO ownership (stored at PI)
- Total: ~3700 heads;

• M1 Edge Sensors developed by FAMES – Fogale / Micro-epsilon (FR / DE)

- 7 batches (77%) accepted and shipped to site
- Total: ~4900 heads;



ETF Storage



M2 and M3 Units

M2 Mirror (@ Safran Reosc, FR):

- **Polishing** progressing with good convergence
- **Surface error** after 5th run: **63 nm RMS** (goal: <60 nm)



M3 Mirror (@ Safran Reosc):

- **Grinding** run#2 completed (<20µm RMS).
- **Polishing** will continue when M2 completed (Q4 2024) to avoid contamination

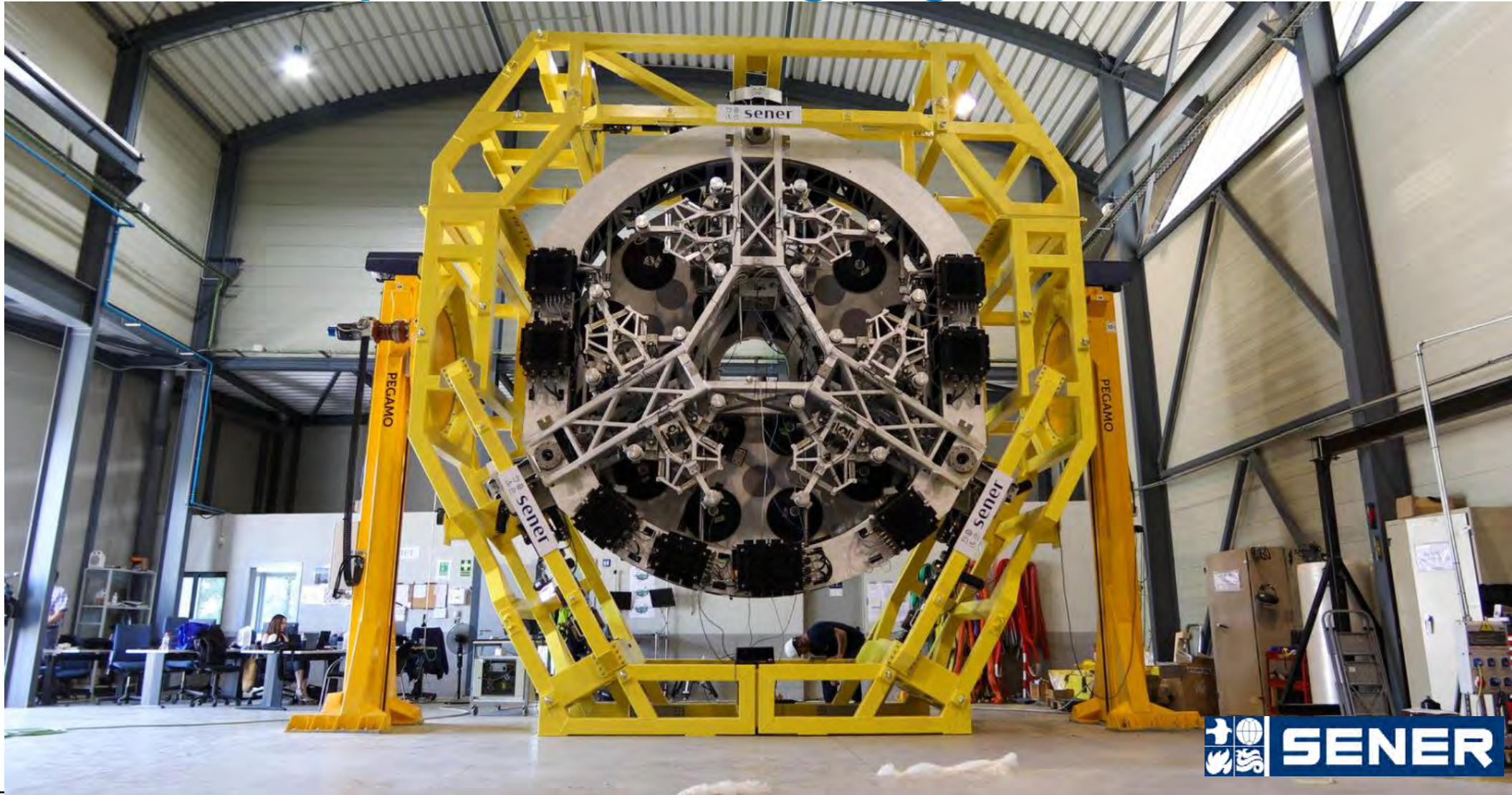


M2/M3 Cell (@ SENER, ES):

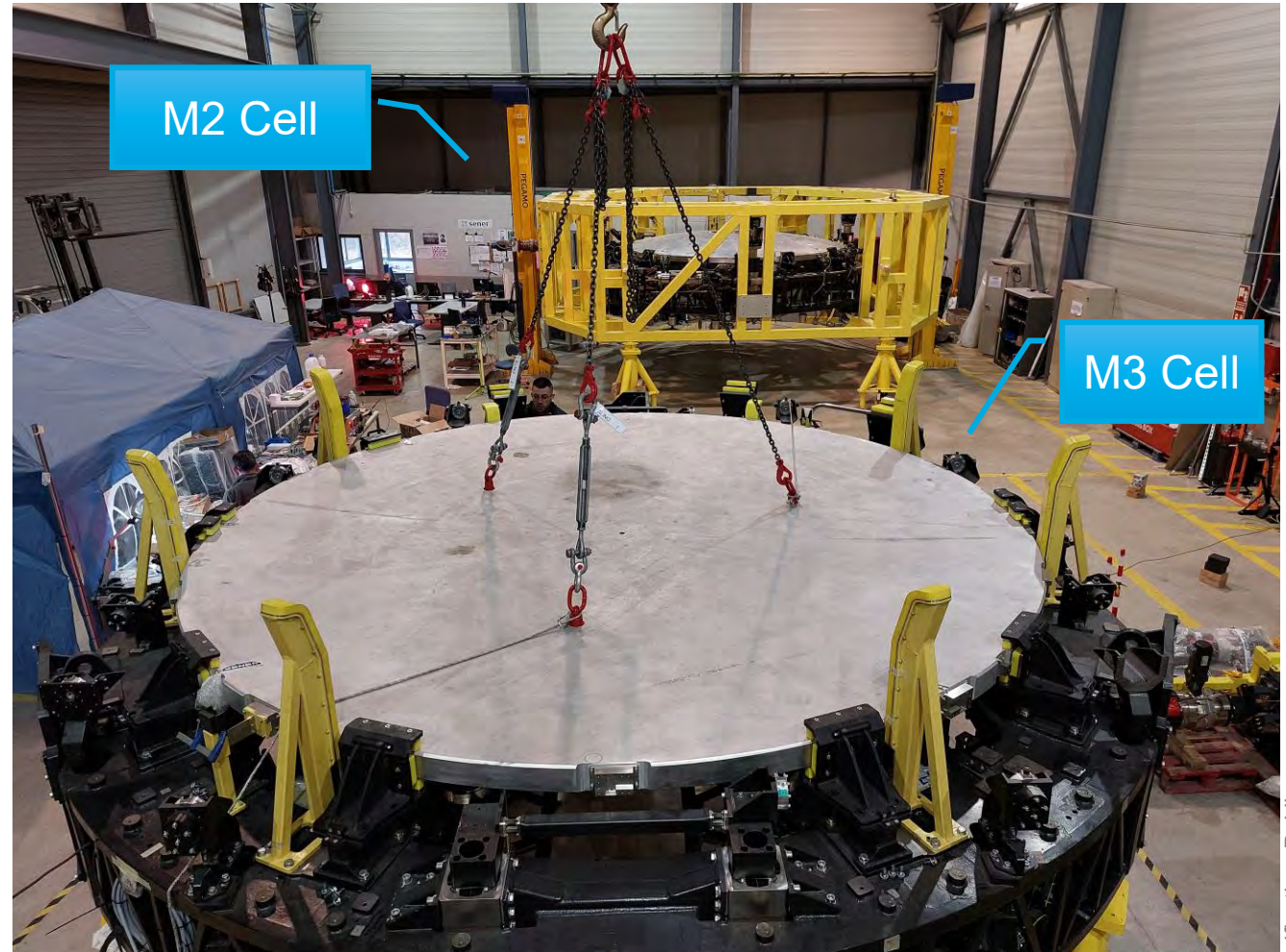
- **M2 Cell Verification tests** on-going with good results so far.
- **M3 Cell** approaching end of integration before testing
- **Auxiliary Equipment** for both Cell: manufacturing completed



M2 Cell acceptance tests on-going



M3 Cell integration reaching completion



M4 Unit (AdOptica, IT)

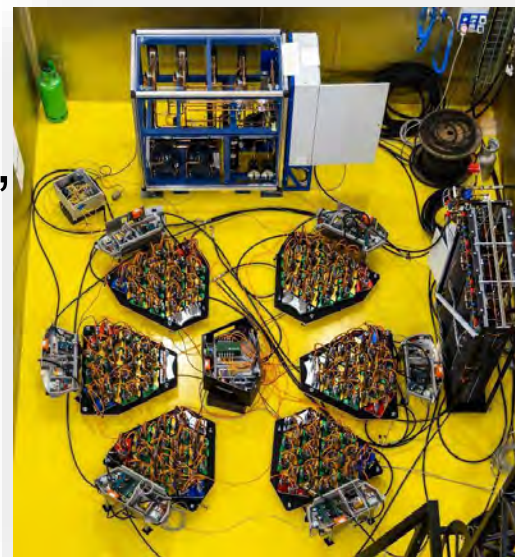
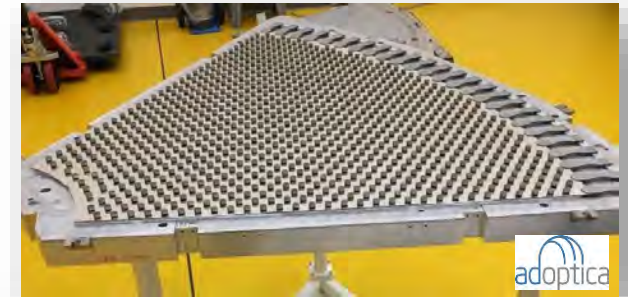


All 6 **M4 Shells** (+ 6 spares) delivered by Reosc to AdOptica

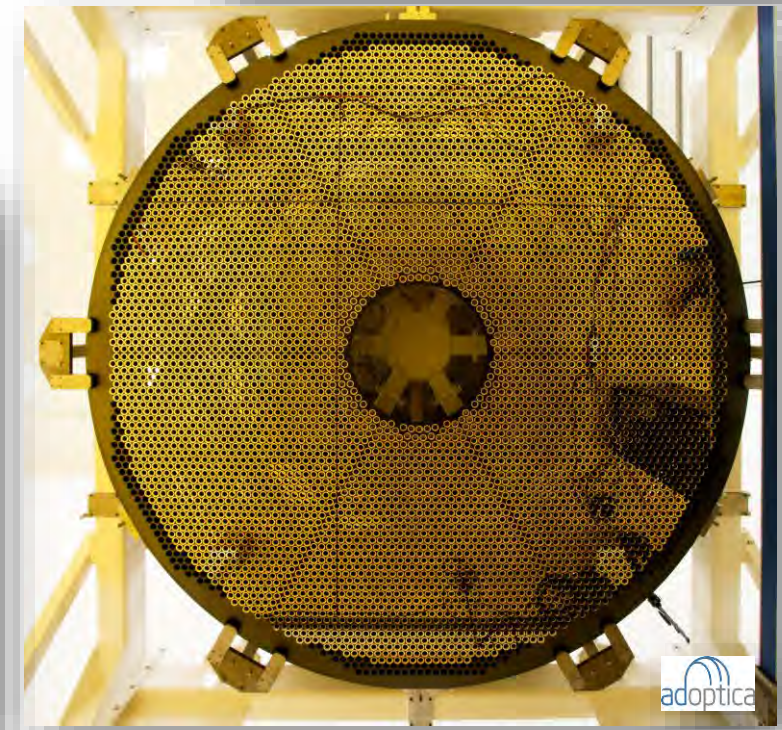
M4 integration proceeding at full speed

- 100% of the Reference Body (RB) with bonded tiles
- Optical Test Tower readiness review successful

Full-scale “white test” of control electronics including bricks, cabinets, cooling, PLC, ... started to mitigate delays in RB readiness (Laser trackers failure, ...)



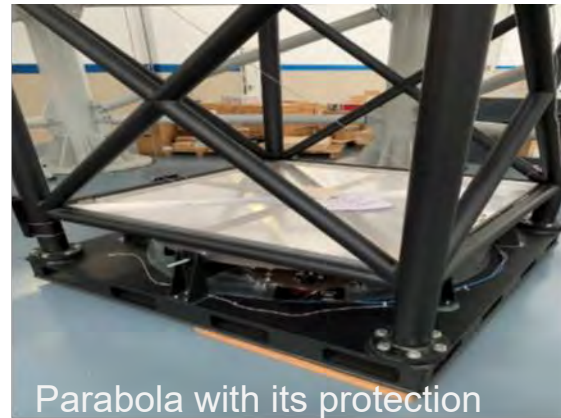
“White test” setup



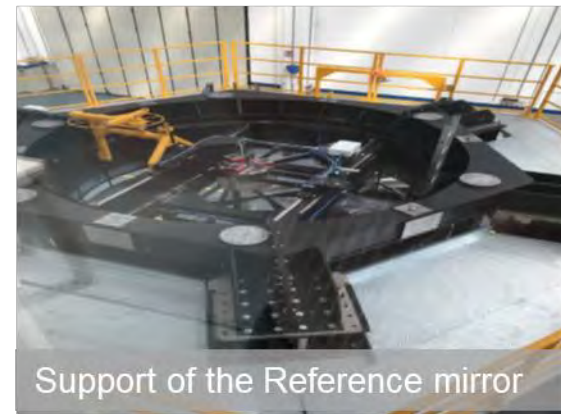
M4 Reference Body – Capacitive Sensing Tiles bonding (100% completed)

M4 Unit integration

Last Shell delivered to AdOptica



Parabola with its protection



Support of the Reference mirror



Integrated M4 Unit with Dummy Mirror

M5 Unit



M5 Mirror (@ Safran Reosc, FR):

- **SiC Blank manufacturing** (@ Mersen Boostec):
 - Brazing & grinding completed; acceptance by Reosc pending
- **Mirror polishing** (@ Safran Reosc):
 - All process & equipment ready to start polishing
- **Mitigation paths** (@Boostec & @ESO):
 - 1- New CVD process
 - 2- Alternative smaller Zerodur® mirror (ESO)



M5 Cell (@ SENER, ES):

- **Acceptance tests** on-going with good results so far.



M5 Cell Electromagnetic Compatibility (EMC) testing by ESO expert – 28/02/2024



Pre-focal Station (PFS) and Phasing and Diagnostic Station (PDS)

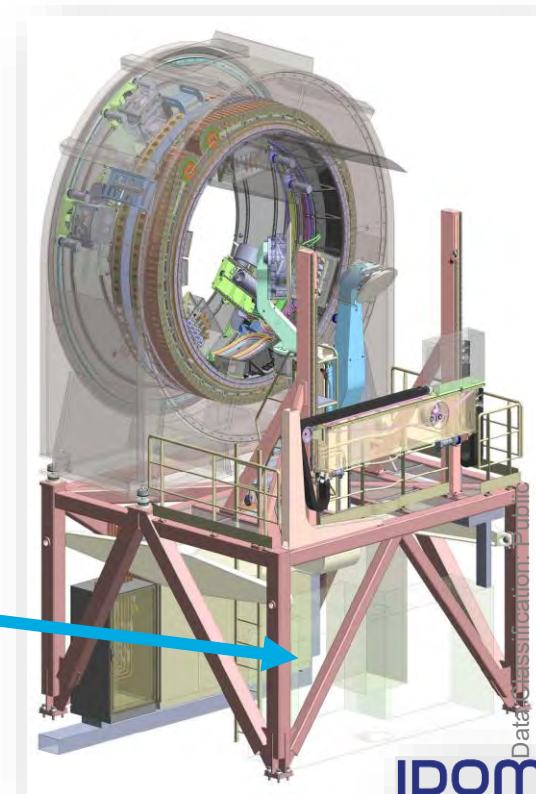
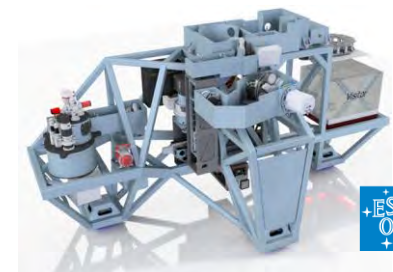


Both **PFS** approaching end of MAIT phase in the large integration facility of IDOM (ES)

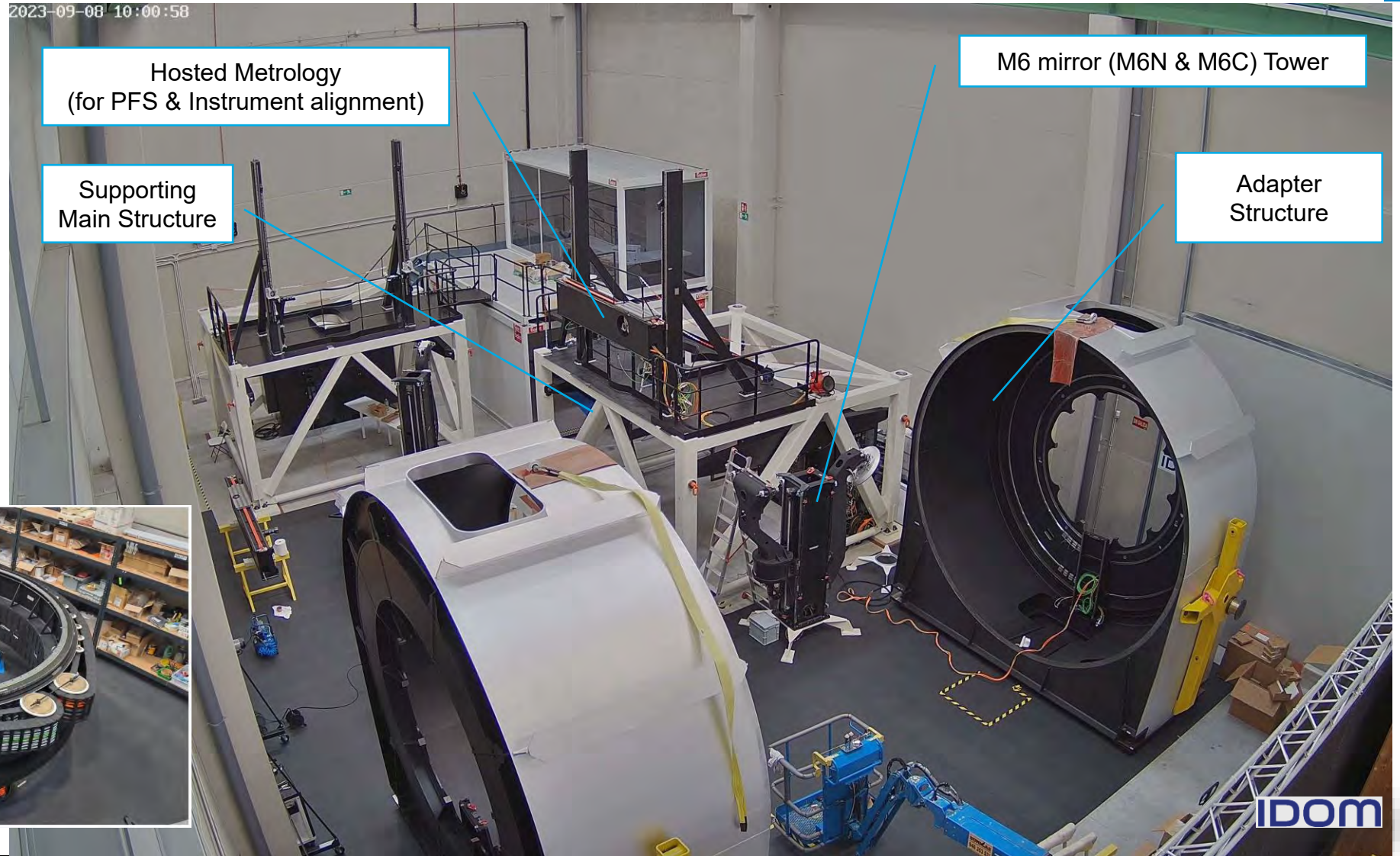
- Factory acceptance scheduled in Q3 2024 to be followed by an ESO test period (TBC) in Q4 2024
- The polishing of the M6 mirrors (2xM6N, 1xM6C) at Glyndwr progressing with delays for acceptance in Q1 2025
- The statement of work is being updated to include options for a test campaign after PAE run by ESO, and an extended storage of the PFSs in Europe
- Option to incorporate a “**petalometer**” sensing arm in the PFS is being studied and specified

The **PDS** (ESO internal) passed Final Design Review in Q3 2023

- All long-lead optics procurement have been placed
- Cryostat mechanics in manufacturing



Pre-focal Station (PFS) – Integration @IDOM, Bilbao, ES



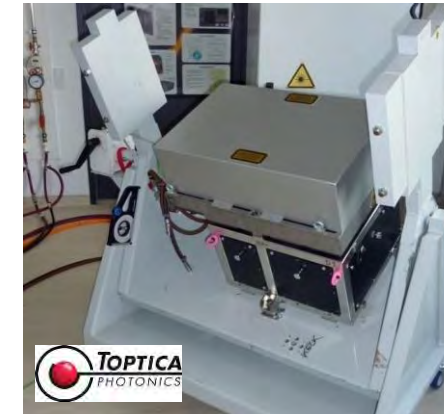
Cable wrap



Laser Guide Star System (6 units)

Laser sources produced by Toptica (DE)

- 9 units ordered (6 ELT + 3 Gravity+); 7th unit received (Dec)



Laser projection subunits by TNO (NL)

- 1st unit manufactured; Verification test on-going

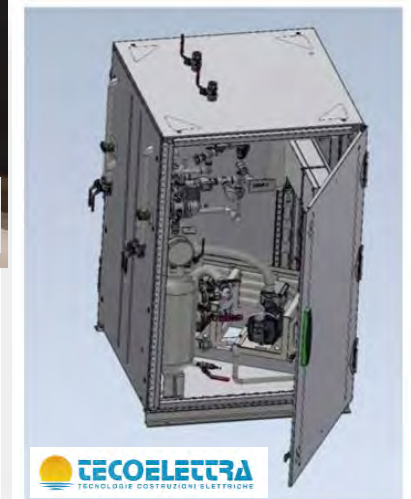
Special Heat Exchanger by Tecoelettra (IT)

- 9 units ordered (6 ELT + 3 Gravity+); all delivered
- Work on-going on PLC controller and vibration mitig.



Aircraft avoidance cameras progressing by Gravity+

- First 2 cameras delivered in Q4-2023 (total: 4 ELT + 8 G+)



Laser pointing camera is waiting for available resources (CaNaPy)



Supporting Equipment (Mirror maintenance, Handling, LN2, etc.)

M1 Segments Coaters (AGC Glass Europe, BE)

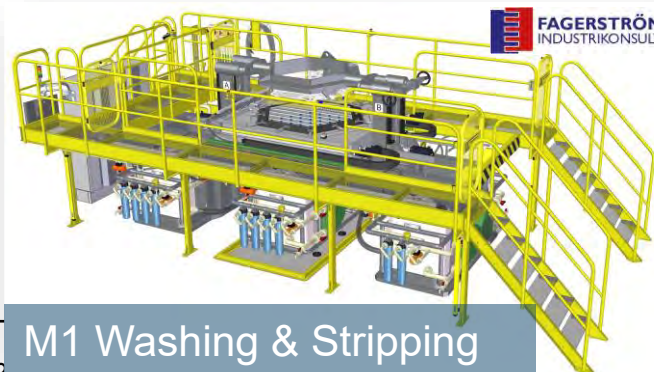
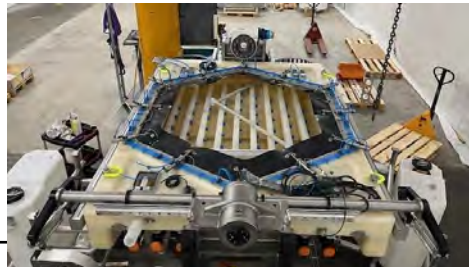
M1 Segment Coating plants (2x):

- The 2 M1 coaters are in **weekly operation** at Paranal (ETF)
- Weekly **remote monitoring** by AGC in place since few months
- **Quality Control Station modification** resulting from M1 SS redesign being implemented (Feb'24)
- **First coating** of “real” M1 segments scheduled for March'24



M1 Segments Washing and Stripping plants by Fagerström, SE

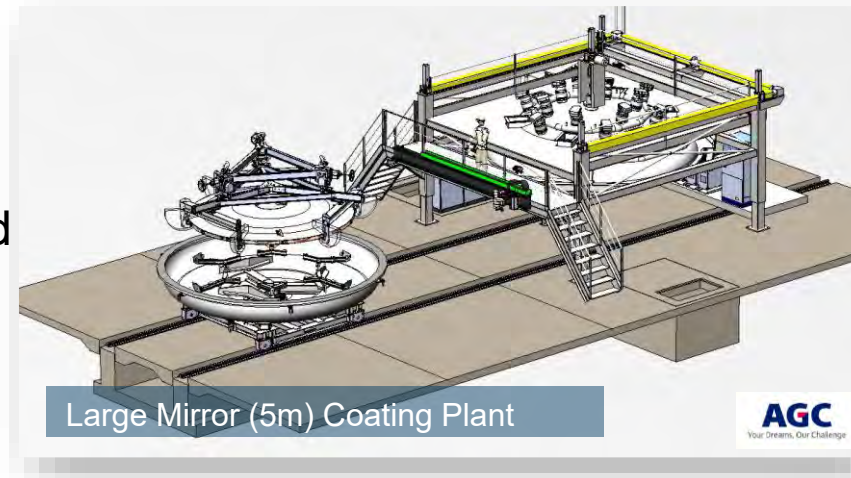
- All components under procurement or manufacturing
- Assembly started in Q1 2024



Large Mirror Coating Plant (LCP)

Large Coating Plant (LCP), by (AGC Glass Europe, BE):

- Most components manufactured
- Assembly to start in Q1 2024
- SiC chemical compatibility study by Danish Institute IPU completed



Large Mirror Washing and Stripping Plant:

- Internal ESO design on-going; mechanical design completed
- FDR foreseen in Q1 2024;
- Call for tender (build-to-print contract) scheduled for July 2024



Large Mirror Washing & Stripping

... and more Support Equipment

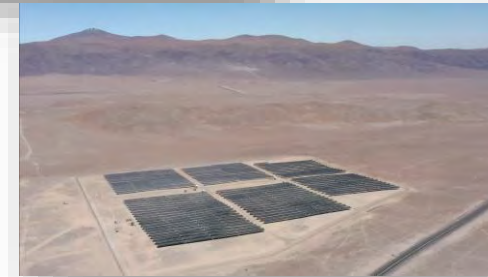
Common handling and lifting tools:

- Trucks, mobile cranes, trailers, mirror transporter trailers, forklifts, boom lifts and special equipment



Power conditioning and backup system:

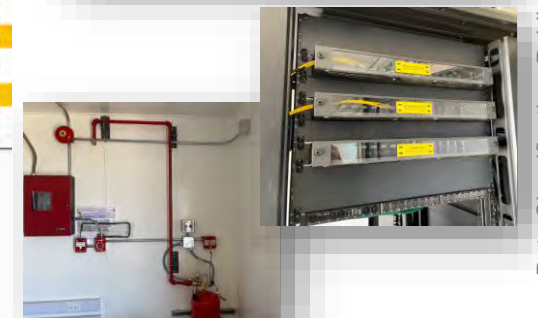
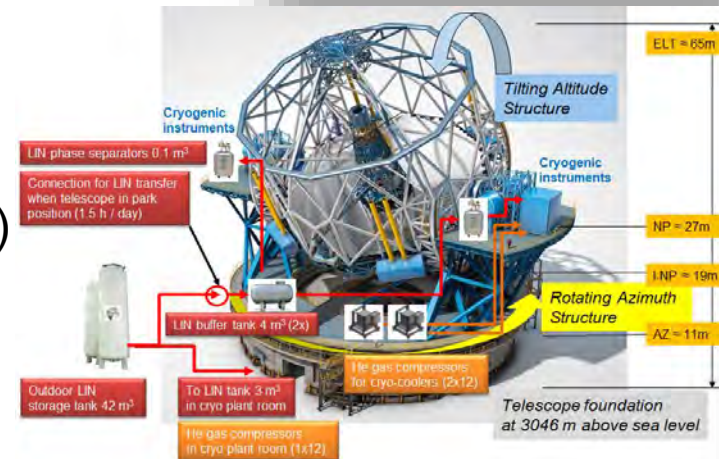
- Photo-Voltaic Plants fully operational
- Power Conditioning System (PCS), being procured by SAESA



Cryogenic infrastructure:

- Contract awarded to AS Scientific Products (UK)

... + ETF Outfitting and more





Instrumentation

ELT First set of Instruments



MICADO

- Diffraction limited **Imager and spectrograph**
- **Near-Infrared** (0.8 - 2.45 μm)
- Resolving power **R~8000**

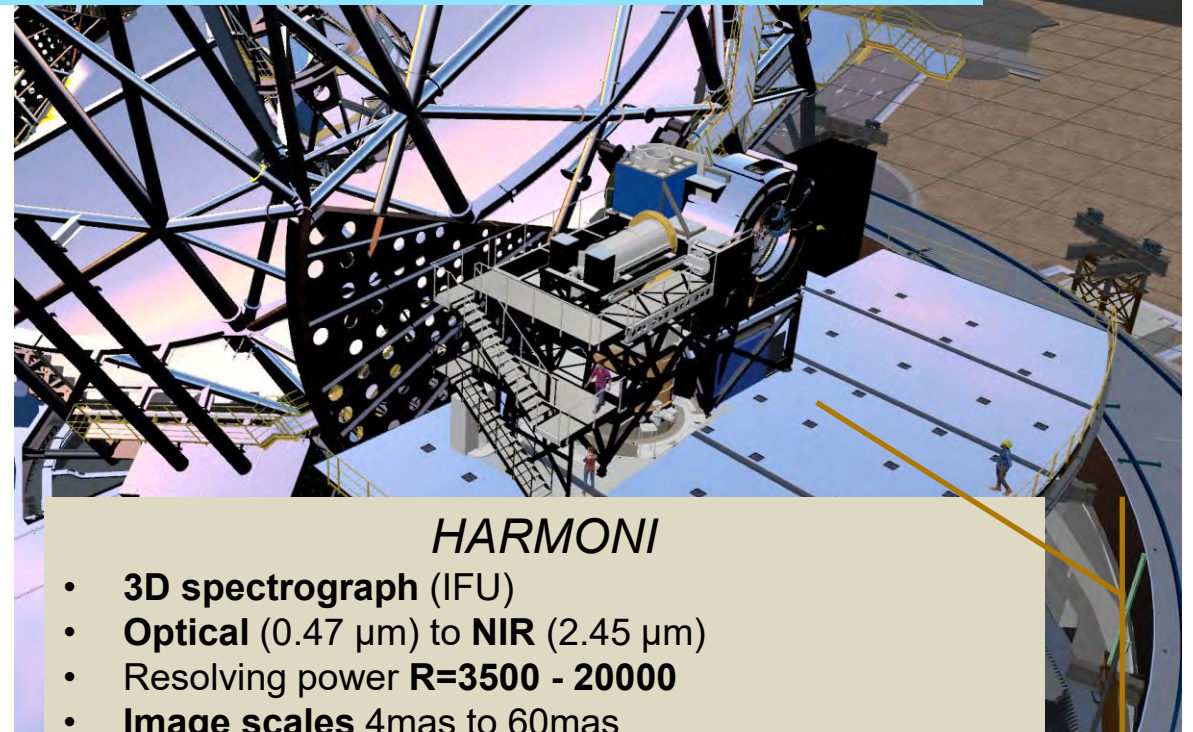


MORFEO

- **Multi-conjugate adaptive optics** module for MICADO
- **2 deformable mirrors** inside instruments
- Wavefront sensing with **3 natural** and **6 laser guide stars**

METIS

- **Imager and (IFU) spectrograph**
- **Mid-Infrared** (3 - 14 μm)
- Resolving power up to **100 000**



HARMONI

- **3D spectrograph (IFU)**
- **Optical** (0.47 μm) to **NIR** (2.45 μm)
- Resolving power **R=3500 - 20000**
- **Image scales** 4mas to 60mas



ELT First Set of Instruments

All four instruments are in the final design phase. Two are close to complete (in 2024) t

MICADO and **METIS** started procurement of certain key components (long-lead items).

HARMONI back on track after **internal restructuring, lift of the Red Flag status**, and good progress towards finding a partner for the **visible channel** (Astralis)

Schedule becoming a **concern** for a Scientific First Light in Sep 2028.

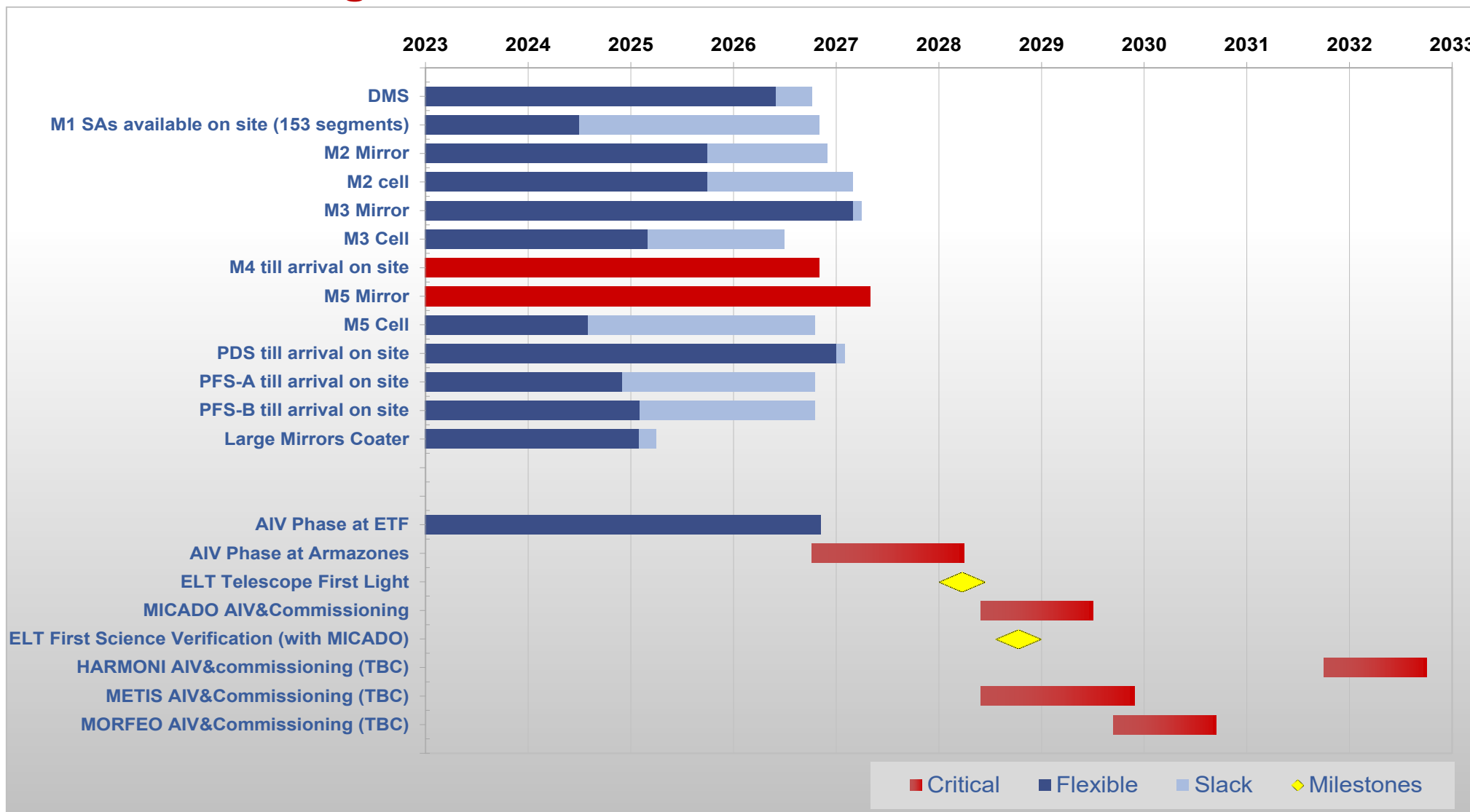
Risk to all instrument costs due to the worldwide situation (high inflation, pandemic, war in Ukraine). Very probable future funding shortfalls



Schedule

ELT Reference Schedule – Critical Path Analysis

Technical First Light: 03/28 - First Science Verification: 09/28



■ ELT Top Level Schedule highlighting in red all the activities on the critical path



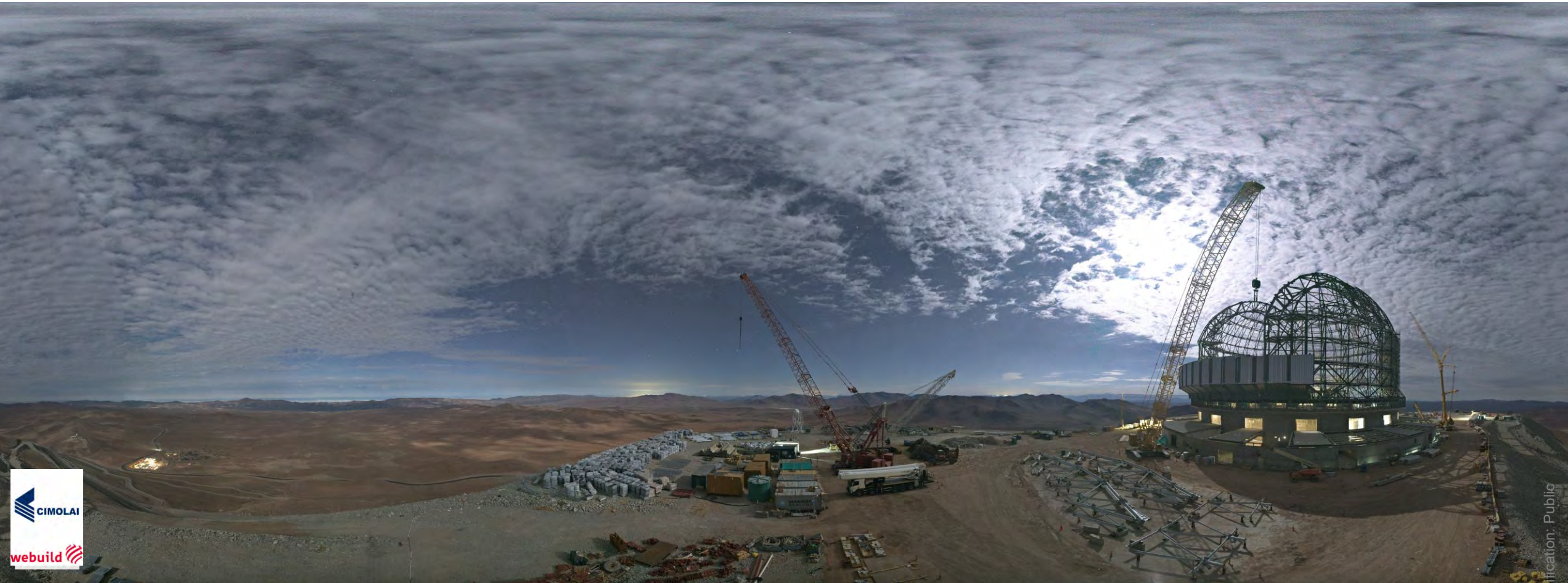
«Thanks for your attention!»



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Data Classification: Public



Overview and update of ESO ELT Construction Project

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ESO ELT Programme Manager

