E-ELT Assembly, Integration & Technical Commissioning

Peter Gray, Emanuela Ciattaglia, Christophe Dupuy, Fernando Gago, Stephane Guisard, Juan Marrero, Rob Ridings, Andy Wright





Introduction

The AIV phase is one of the major challenges of E-ELT

- E-ELT AIV is the activity of assembly, integration, testing, troubleshooting, debugging, tuning and verification of the sub-systems to deliver an operational EELT telescope and the suite of first light instruments technically capable of delivering the top-level requirements and ready to start science commissioning leading to operations.
- The scale & complexity of the E-ELT means that AIV involves considerable logistical and scheduling challenges
 - > 798 mirror segments. Staged delivery over 4years. Integrated & coated
 - > 4,524 edge sensor pairs, 2,394 position actuators tested & installed
 - ten major sub-systems; the M2-3-4-5 mirror units, PFS & Lasers
 - > four major new instruments to be integrated, installed & commissioning





- E-ELT Overview & AIV Strategy
- Facilities, Equipment & People
- Detailed Planning & Schedule
- Dome & Telescope, Opto-Mech M2-3-4-5 & M1 Segments
- Installation & Alignment in Telescope
- Technical Commissioning
- Instruments AIV
- Science Commissioning & Hand-over to Operations



EELT Telescope





E-ELT AIV Strategy

The EELT Programme has organized the AIV phase as a project

- Under responsibility of Project Manager ('AIV Manager')
- With a defined Budget, Staffing/FTE & Schedule
- Includes all technical activities that occur on-site at Armazones/Paranal
- Deliverables to AIV on-site from project contractual procurements
 - > i.e. dome/telescope, optics, (control SW), infrastructure, handling equipment
 - Contract project managers have responsibility up to time of delivery on-site
- AIV Phase includes final system tests of the completed telescope ('Technical Commissioning'). Delivers a working EELT at 1stLight on a Test Camera, ready to start Science Commissioning
- AIV phase ends with the handover of the completed telescope with installed instruments to the start of Science Commissioning
 - responsibility then passes to the Science Commissioning team



AIV-SciComm-OPS





E-ELT AIV Ingredients

PLACES PEOPLE PARTS PROCESS





E-ELT AIV Ingredients

PLACES PEOPLE PARTS PROCESS



Support Facilities & Work Areas

- One challenging aspect of AIV is having sufficient work spaces & equipment to perform multiple AIV activities in parallel
- ESO will support (most) E-ELT AIV & future operations technical activities from Paranal Observatory
 - Minimal support infrastructure at Armazones
- Auxiliary Building surrounding the E-ELT dome
 - Large Entrance Hall & Instrument Assembly Area with cranes & utilities
 - > Facilities designed primarily for operations. Need use of all space for AIV
- New EELT Facilities at Paranal
 - E-ELT Mirror Facility for integration & coating of M1 segments & M2-3-5
 - > E-ELT Technical Building purpose-built for processing M1 components
 - Segment Storage Yard large fenced area for staging/storing M1 segments

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Armazones Instrument Assembly Area & Entrance Hall



EELT AIV Workshop 14, 23, 24 June, 2016 ESO-286946

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Lifting & Handling Equipment

- Facility cranes 20-10-5T in dome & work areas
- Self-propelled mobile platforms for large loads inside
- Truck transportation. Road Paranal-Armazones 30km 8%
- "Swap-Body" trailers for large loads M2-3-5
- M1 segments in transport containers
- Multiple forklifts 8-5-2T. Man-lifts, cherry-pickers, scaffolding





Lifting & Handling Equipment



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E-ELT AIV Ingredients

PLACES PEOPLE PARTS PROCESS

SPIE Conf. "Astronomical Telescopes and Instrumentation" June 2016; Paper 9906-32

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AIV People

The most important resource for E-ELT AIV is the people

EELT AIV schedule is paced by the availability of technical staff

AIV work falls into several skill sets and expertise areas:

- ➤ repetitive procedures e.g. installation & alignment of M1 fixed frame; M1 control electronics & cabling; etc. → outsourced as contract work
- ➢ integrating, troubleshooting and tuning complex opto-mechanical systems i.e. M2-3-4-5-PFS systems → requires experienced senior engineers
- ➢ general technical support activities i.e. transport, lifting, loading, assembly, installation, maintenance → performed by general observatory operations staff

AIV Staffing by:

- > New ESO Paranal recruitments. Transition from AIV \rightarrow OPS Support
- Contracted outsourced effort for straightforward, repetitive tasks
- Additional engineering support from ESO Garching technical staff



AIV Staff FTE Estimation

EELT AIV - Staff Estimates - v.9																																									
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2016-06-14, AIV Workshop – Staff, Facilities & Work Areas

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E-ELT AIV Summary (1)

AIV phase starts 4-5 years before final telescope assembly

- Arrival of M1 mirror segments & components. Production spread over several years
- Unpacked, inspected, pre-coat, integrated & tested using an assemblyline process. Made ready for direct telescope installation. In storage
- Delivery of M2-3-5 mirror cells & positioning systems. Unpack, re-assemble & test with mirror dummies
 - > Later shipments M2-3-5 mirror optics. Unloading, pre-coating & storage
- Dome & Main Structure contractor constructs a "turn-key dome & telescope structure
 - Hand-over to AIV at Preliminary Acceptance. Dimensional checks & reverify key performance requirements



E-ELT AIV Summary (2)

- Install & align 798 M1 interface frames on telescope M1 cell
 - Long complicated process. 12+ months continuous work
- Install & cable M1 control electronics, then position actuators
- Start installing pre-coated M1 segment from stored backlog
 Continues for 12-18+ months. Delivery last batches just-in-time
- Installation & alignment Pre-Focal Stations & WFS systems
- Telescope installation M2-3-4-5 with mirror dummies & testing
- Remove M2-3-4-5 sub-units & replace with real coated glass
- Begin Technical Commissioning with Test Camera. 1stLight
- Installation & alignment EELT Instruments



Detailed Planning & Scheduling of AIV Activities

- Detailed AIV phase schedule has been developed which breaks down tasks into steps (typically in fractional hours) and links up activities with interdependencies
 - > Uses Deltek Open Plan_{®.} Fully linked to main E-ELT project schedule
 - ~2,500 individual AIV tasks. Equal size to overall schedule
- Bottoms-up analysis of long duration repetitive tasks
 - e.g. installation of 798 interface frames, involving tasks of 10-15min duration by teams of 2-3 people, with a total duration of ~12 months
- Resource loading & timing of multiple concurrent activities
 - Identifies criticality of key resources such as integration work areas, handling equipment & telescope access availability
 - Used to analyse optimum staffing plan. Identifying required skills and timing of conflicting activities



E-ELT AIV Schedule

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08.10.15.02	EELT AV Team - establish early AV team for Paranai AV prep	U	01948y2020	01May2020					
08.10.15.03	EELT AVY Team - mobilise & build up on Armazones	507d	173812022	15May2024					
00.10.15.04	ESO-provided M1 Dummy Masses for Main Structure assists DBMS contractor	75d	260ct2020	09Feb2021					
08101505	ESO Monitors Contractor's Main Structure Survey	1004	25May 2023	120ct2023					
08.10.15.06	Main Structure A/V	394d	01Mar2022	045eo2023					
08.10.15.07	Done AV	204	26May/2023	07.442023					
08 10 15 08	Prove System & Distrikt tion - 40/ Verification	794	25May 2021	135en2021					
08 10 15 09	Site Monitorino Facilities (SME) - Instalation & Commissioning	421.4	01Mar2022	110/12023					
00101510	Mi Cooling System - Ally Test & Verification	717d	15.hm2021	194x2024					
08101511	I N2 Instrument Conline Sustein - AD/ Text & Verification	1104	295 em 2023	01Mar2024					
08.10.15.11	Conservational Me Instrument Conding System - Part Test & Verification	204	182402025	28042024					
00.10.15.12	Mi Contro For Brief (Record FMF) - All Constructions & Testico	3051	015-02019	17.1.20024					
08101514	MI Costing Facility #2 (Paranai EME) - AI/ Commissioning & Testing	304	015ae2021	13042021					
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08:10:15:15	Mi Washing Unit #1 - Any Commissioning & Testing	204	01042020	200-42020	·				
00.10.10.10	ELE Manual III. All Completing & Testing	1124	01042021	1044-2020					
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08.10.15.20	EMP on. Coating Hart - Commissioning & Tetting	1670	013022022	21Fe02023					
08.10.15.21	M2 Cell & Positioner AIV - Delivery & Integration - PAR at EMP	436.510	10Mer2022	10Nov2023					
00.10.15.22	MJ Cell & Postioner AIV - Delivery & Integration - PAR at EMF	3121.56	1 07Dec2011	070ec2023		1			
08.10.15.23	LUS Projection Units AIV - Delivery & Integration - APM IAA Area	060	01Dec2023	01Apr2024					
08.10.15.24	LOS Laser Sources AIV - Delivery & Integration - APM IAA	1288	01Dec2023	29Moy2024					
08.10.15.25	M4 Algoment Duniny (M4AD) ATV	308	200et2023	01Dec2023 P					
08.10.15.26	M4 Unit - Contractors On-Site AIV 8 ESO Acceptance	491d	01Dec2021	200et2023 P					
08.10.15.27	M4 Unit - ESO AIV	221d	01aun2023	05Apr2024 1					
00.10.15.20	M2 Mirror - Delivery, Coating & Storage	204.410	1 21Feb2023	25Mar2024 1				(
08.10.15.29	M3 Mirror - Delivery, Coating & Storage	31.41d	09Feb2024	25Mor2024					
08.10.15.30	MS Mirror - Delivery, Coating & Storage	16.41d	15Jan2024	06Feb2024 7					
08.10.15.32	MS Mirrors - Re-Coating with Fresh Silver Coating	4.16d	04Jun2024	11Jun2024					n
08.10.15.38	Edge Sensors - Unloading, Inspection & Storage	714d	20Feb2020	21Nov2022 P					
08.10.15.39	M1 Segnent - Unloading & Storage in Segnent Storage Yard SSY	1094d	18Mer2020	31May2024			1	1	
00.10.15.40	M1 Segnent Coating & AIV - Unpacking, Coating, Edge Sensor Install & Re-	1106.30	1 01 Apr 2020	220ct2024 1			11 1	I	
00.40.45.40	Storage	4474	045	101-2002					
08.10.15.43	Mi Forei France - Unloading, Unpacking & Inspection	1420	010602022	1930h2023					
00.10.15.44	Mil Posteri Actuators PAULI - Unidening, inspection, rest & storage	317.7.05	04H892020	007602024					
00.10.15.45	Veriny sate MI Segners storage a Handling	100	20469/2021	073052021					
08.10.15.46	Initial Telescope Survey & Phase 1 Alignment	6788	1538/2021	24A0g2023					
08.10.15.47	M2-3-4-5 Shim Adjustments - Calculate & Machine	790	03302023	200012023					
00.10.15.40	Segment Grane - Install 11 Winch & Test Grane	50	20May2023	023062023				U	
08.10.15.49	MI Fixed Frame Installation & Alignment	188.316	3 23Jun2023	13Mar2024					
08.10.15.50	M1 Control Installation & Cabling	318.450	1 15Mar 2023	033042024					
08.10.15.51	M1 Menipulator & Phasing Gun Installation	161d	01Dec2022	14Jul2023					
08.10.15.52	PACT Installation in Telescope	443.296	1 26Dec2022	065ep2024					
00.10.15.53	MI Segnerz Assembly - Practice Installation with MI Duninies	217.096	000442023	02Nov2023					
08.10.15.54	Installation-ready M1 Segment - Available	948.090	03Mar2021	220ct2024 P					
08.10.15.55	MT Segment Installation in Telescope	423.816	22Mar 2023	04940-/2024 /					
08.10.16.66	MI Centrel Teste, Calibration 8 Leop Optimisation	33674	070ec2011	01N6v2024 #					1
08.10.15.57	Installing M2 Electronics & Cabling on Telescope - Lower Structure	0.55d	27Feb2024	28Feb2024					
08.10.15.58	Remove Durnny M2 Unit from Telescope	199,686	1 26Mey2023	29Feb2024 1					
08.10.15.59	Installing M2 Electronics & Cabling on Telescope Top End Structure	\$9.36d	11Dec2023	01Mar2024					
08.10.15.60	Install M2 Unit with M2 Dummy Mirror on Telescope	3186.16	07Dec2011	07Mar2024					
08.10.15.61	Removal Durniny M3, M5 & M4 Units from Telescope ART Tower	206.676	1 26Mey2023	11Mer2024					
08.10.15.62	Instal M4 Alignment Dummy in Telescope ART Tower	72.50d	01Dec2023	12Mar2024					
08.10.15.63	Installing M3-5 Electronics, Cabling & Cooling in Telescope ART Tower	291.176	01Feb2023	14Mar2024 /					
08.10.15.64	Integrate MS Unit & Install Dummy MS Mirror	68.11d	16Jan2023	20Apr2023 1					
08.10.15.65	Instal MS Unit with Dunmy Mirror in Telescope ART Tower	293.396	01Feb2023	16Mar2024 1					
08.10.15.66	Install M3 Unit with Dummy Mirror in Telescope ART Tower	123.026	020et2023	21Mar2024					
08.10.15.67	Rebalance Telescope after M3-4-5 Unit (Dummy Mirror) Installation	4.05d	21Mar2024	27Mar2024					0
08.10.15.69	Functional Telescope Testing N2-3-4-5 with Dummy Mirrors	534.520	15Apr2022	02May2024					
08.10.15.70	Telescope Alignment - without Optics	30d	27Mor2024	08May2024					
08:10:15:71	Removal M2 Unit & Dummy Mirror from Telescope	49.43d	04Mar2024	13May2024					
						1			
08.10.15.72	Instal M2 Mirror in M2 Cell	338.104	01Feb2023	20May2024					
08.10.15.72	Install M2 Mirror in M2 Cell Install M2 Unit with M2 Mirror in Telescope	338.10d	01Feb2023	20May2024 1 22May2024 1					



Detailed AIV Tasks

2 010110451001	10														2021				-		2022							2023			
7 USUS 10.45.100.1	lu Antivitri Dana	Ouratio	o Each Start	EacheEiniel		EPA Bradasassore	EPO Puttosesso	- ñ	, he [.e.	a San	Oct Nov Dec	Jan Fab	March	ing Max	100	Aug (Sen Or	Nov Dec	Inc. Each Mar A	or Max	2022	Can	Oct Nov	Dec	Inc. Eab	Mar Arr	Mary Av	2025	Aug Cer	04	Nov Dec
00.10.15.21	MO CALL DOUBLING ADV - Dalbary & Manadation - DAID at EME	416-014	n cany start	1084/2022	None	_ESO_Predecessors	_ESO_SUCCESSORS	BL	~ [~	Al Seb [our new rose	San reo	max 1 A	φε [may		1400	Sep OC			the Linear	y laar laar jaag	Seb	1 101	- Lose -	an reo		are in		AND 134		SIL
08.10.15.21.02	Needed to start - M2 Unit AIV - Delivery & Integration	4204	10Mar 2022	190ct2023	None				\vdash		-					-++				- 1	1 1	_	1 1011	1 1 11			111.11		1 11 1 11		
08.10.15.21.02.10	EMF Mirror Litt - testing with M2 Dunny Mirror completed	0	10Mar2022	10Mar2022	None	08.10.15.17.95,Finish to Start	08.10.15.21.05,Finish to Start												4												
08.10.15.21.02.15	EWF 5m. Working Area - ready for M2M3 cell integration	0	01Jun2023	01.Jun2023	None	08.10.10.18.50.15.70 Finish to	08.10.15.21.05 Finish to Start																								
	AND Records around a few AND and intermediate in Fight, second Ballin A					Start			\square		_	\square				\rightarrow					++			111			-##T				
08.10.15.21.02.16	401 Truck - restry for M2 cell integration in EW - resp. INPICA Super Body Trailer (SBT) - resets for M2 cell integration of EWE - restr	0	01A0g2023	01A0g2023	None	08.10.10.22.20 Finish to Start	08.10.15.21.05 Finish to Start		\vdash		-					\rightarrow	-++						+ ##+	+++							
00.10.10.21.02.17	NFRA	ľ	000000000	00002020	1404.10	00.10.10.22.30/110110 3001	00.10.10.21.00/110110.0001	1.1																				TT H		11 11 1	
08.10.15.21.02.18	Flat Platform Transporter (FPT) - ready at EWF for M2 cell integration - resp. N#RA.	0	15Aug2023	15Aug2023	None	08.10.10.22.50,Finish to Start	08.10.15.21.05,Finish to Start																						•		
08.10.15.21.02.19	Trailer Caddy (TRC) - ready at EMF for M2 cell integration - resp. NFRA	0	17Jul2023	17Jul2023	None	08.10.10.22.40,Finish to Start	00.10.15.21.05,Finish to Start																								
08.10.15.21.02.20	Scattolding & Ladders - ready for use at EMF - resp. INFRA.	0	21 Aug2023	21Aug2023	None	08.10.10.22.167 Finish to Start	08.10.15.21.05,Finish to Start																				1111		4		
08.10.15.21.02.21	35T Grove Crane - existing Paranal - available for EELT use	0	17Oct2023	170et2023	None	08.10.10.22.170 Finish to Start	08.10.15.21.05,Finish to Start	11																1			1111				
00.10.15.21.02.24	M2 Cell shipment - arrives Paranal	°	190ct2023	190ct2023	None	08.10.10.10.11.55,Finish to Start	00.10.15.21.05,Finish to Start														1 1						1111				
08.10.15.21.02.30	M2 Unit Transport Container (M2TC) - arrives Paranal	0	25Sep2023	25Sep2023	None	08.10.10.10.11.61 Finish to Start	08.10.15.21.05,Finish to Start																							4	
08.10.15.21.02.35	Outside Storage Area (OSA) Paranal - ready for storing empty M2 shipping boxes	0	01Sep2023	01Sep2023	None	08.10.10.18.50.50.10,Finish to Stort	00.10.15.21.05,Finish to Start																						•	-	
00.10.15.21.02.40	M2 Mirror Dunnty - needed for AIV - M2 cell integration	0	01May2023	01May2023	None	08.10.10.10.11.85,Finish to Start	00.10.15.21.05,Finish to Start																							-	
08.10.15.21.02.50	M2 Mirror Stand - needed for AIV - M2 cell integration	0	23May2023	23May2023	None	08.10.10.10.11.74 Finish to Start	08.10.15.21.05,Finish to Start		\square																		WH.				
00.10.15.21.02.60	M2 Mirror Handling Tool - needed for AIV - resp. INFRA - M2 cell integration	0	24May2023	24May2023	None	00.10.10.10.50.15.56 Finish to Start	00.10.15.21.05,Finish to Start		\square																		*				
08.10.15.21.02.70	M2 Minc electronics & cabling - evalable & ready for M2 unit AIV	0	15Aug2023	15Aug2023	None	08.10.10.10.11.58,Finish to Start	08.10.15.21.05,Finish to Start									П													-	-	
08.10.15.21.02.80	M2 Control HW/SW Ready - for M2 Unit A/V in EMF	0	01.Aug2023	01Aug2023	None	08.10.10.15.38,Finish to Start	08.10.15.21.05,Finish to Start																							-	
00.10.15.21.02.90	EELT CS Model - Paranal EELT Mirror Facility (EMF) - ready for M2 Unit	0	01Sep2023	01Sep2023	None	00.10.10.15.255,Finish to Start	00.10.15.21.05,Finish to Start																						× .	-	
08.10.15.21.05	M2 Unit AIV - ready to start	0	190ct2023	190-12023	None	08.10.15.21.02.10.Finish to	08.10.15.21.10.Finish to Start				-										-		+ ##	+++							
						01.00 21.02.00 // mem ho 01.01 23.21.02.20 // mem ho 51.01 52.21.02.20 // mem ho 51.01 52.21.02.20 // mem ho 50.10 52.21.02.50 // mem ho 50.10 52.21.02.10 // mem ho 51.01 52.21.02.21 // mem ho 51.01 52.21.02.21 // mem ho 51.01 52.21.02.20 // mem ho																									
08.10.15.21.10	Unloading M2 cell in shipping crate from truck using 35T Grove crane	.15d	190ct2023	190ct2023	None	08.10.15.21.05,Finish to Stert	08.10.15.21.15,Finish to Start																							1	
00.10.15.21.15	Unioading M2 Transport Container (M2TC) from truck	.13d	190ct2023	190ct2023	None	08.10.15.21.10,Finish to Start	08.10.15.21.16,Finish to Start 08.10.15.21.35,Finish to Start																							P	
08.10.15.21.16	Unioad M2 positioner 8.M2 Mntc Bectronics/Cabling in shipping cristes from trucks	0.08d	19Oct2023	190ct2023	None	08.10.15.21 15 Finish to Start	08 10 15 21 20 Finish to Start							1																1	
00.10.15.21.20	 Commence anapping creates the M2 cell & M2 (C. Cean & Inspect for transport damage. Move the Del Del transport or Transport of the Del 1 (2010) and 1000. 	0.400	190012023	19062023	None	00.10.15.21.16 / mith 10 Start	00.10.15.21.21 pintsh to Start				_					\parallel														13	
08 10 15 21 22	using 35T grove crane. Remove fit of M2TC outside PMF and store	0.114	190/12023	200/12023	None	08 10 15 21 20 Filling to Start	08.10.15.21.22 Finish to Start				_																			13	
08.10.15.21.25	Lift M2 Cell into M2TC using 3ST Grove crane	0.14d	200ct2023	200ct2023	None	08.10.15.21.22.Finish to Start	08.10.15.21.30 Finish to Start		\vdash		-					++					+ +		+ #	+++							
00.10.15.21.30	Move M2 cell loaded in M2TC into EMF working area using FPT	0.094	200ct2023	200et2023	None	00.10.15.21.25,Finish to Start	08.10.15.21.50,Finish to Start	-H								++								111						14	
08.10.15.21.35	Unpack & clean M2 positioner & electronics cabinets inside EMF. Inspect	0.21d	190ct2023	190ct2023	None	08.10.15.21.15,Finish to Stert	08.10.15.21.40,Finish to Start																	110						H	
08.10.15.21.40	for transport damage. Connect M2 electronics cabinets to EMF utilities power, cooling & network	0.17d	190ct2023	190ct2023	None	08.10.15.21.35,Finish to Start	08.10.15.21.45,Finish to Start	\vdash	\vdash				\square	++		+					-	+	+	$\left\ \cdot \right\ $			$\parallel \parallel \parallel$				
10 10 15 31 15	Browner on Mit also benefic & compart to ED 7 / C moder from the	0.974	10042022	10040000		00 10 15 01 40 Eulip 1- 01-1	09 10 16 11 50 Exclusion 14 71-1				-					\rightarrow							1	111							
08.10.15.21.45	 Former variant departments a connect to test in use of the basic functionality. Link Schedul 22 participant laws on M2 call Casida M2TC* 	0.804	200/42022	230/42023	None	08.10.15.21.40 (189110 Start	08.10.15.21.50 Printsh to Start				_												1							B	
No. 10.12.21.30	uni o envire da possioner lega on lea cel (naide lea c)	3.000	2000t2023	a 30012023	PROFILE.	00.10.10.21.40 / man 10 58M	00.10.10.21.00/ monito 500t		1 1		1			- 11		- 11		11		I I	1 1		1 111	110							(II I I



E-ELT AIV Ingredients

PLACES PEOPLE PARTS PROCESS





Armazones Site





EELT Telescope & Dome



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Dome & Main Structure (D&MS)

E-ELT Dome & Main Structure delivered as one large single "turn-key" design-build-install contract

- Handed-over to ESO AIV as a fully-operational dome & telescope structure which slews & tracks to specified requirements suitable for astronomical use
- Frees up AIV from a significant part of the large construction activities. Allows ESO to concentrate on the difficult telescope optics specific work
- Includes the Auxiliary Building surrounding dome. Used for AIV activities
- D&MS Acceptance testing will involve a number of tests and dimensional verifications
 - Participation by ESO AIV staff kick-start the hand-over at start of AIV phase
 - > Dimensional verification an important precursor to AIV telescope alignment
- Contractor acceptance testing using own control system
 - Following acceptance, ESO installs E-ELT Control System, tests & verifies













Sub-System AIV M2-3-5 & LGS

Each major EELT sub-unit procured as turn-key sub-system

- Fully tested & verified in Europe during acceptance
- Partially dismantled & shipped to Chile
- Re-assembled, tested & verified by AIV at off-telescope facility (in Paranal)
- M2-3-5 Mirrors procured & separately from Cell-Positioner
 - Inspected on arrival, then coated in E-ELT Mirror Facility in Paranal
 - Stored temporarily in transport boxes, ready for installation
- Laser Guide Star (LGS) units are modular & compact
 - Tested, tuned & accepted in Europe, then shipped to Paranal
 - Unpacked & tested. Straight-forward telescope installation
 - Copies of existing system developed for VLT







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Sub-System AIV M2-3-4-5 & PFS

Pre-Focal Station is large sub-unit with multiple sub-systems

- Includes guiding & wave front sensing
- Sub-assemblies will be installed & aligned directly on Nasmyth Platforms
- > Modules pre-tested in Europe, shipped, then re-assembled & tested

M4 Sub-Unit is complex sub-system with fragile components

- Contractor responsible for on-site re-integration & testing
- Acceptance and hand-over to AIV, just before telescope installation



Mirror Segments, Edge Sensors & Position Actuators





4,424 Edge Sensor Pairs

798 Mirror Segment Assemblies



2,394 Position Actuators



M1 Mirror Segments, Sensors & Actuator Components

- Procurement-shipment-unpacking-inspection-test process for large quantities of M1 components
 - > 798 mirror segments. Delivered over extended four year period
 - Coated & integrated to be fully telescope-ready. Storage yard
 - > Inside custom-designed transport containers. Inert gas sealing preserve coat

Edge Sensors

- > ~9,000 individual units. Shipped over three year period
- Inspected, tested & logged in product database

Position Actuators

- ~2,400 precision actuators. Individually inspected, tested & stored
- Utilize industrial mass-production approach
 - Dedicated facility at Paranal. Automated processes & test equipment
 - Teams of technicians contracted specifically for these activities



M1 AIV Strategy

M1 AIV & installation is by far the largest, longest, most complex activity of E-ELT AIV

ESO is the "prime" contractor. Responsible for M1 "unit"

- Installation & alignment of M1 segments is on the critical path in final AIV phase ~12 months long (Nov2023-Nov2024)
- M1 segment assemblies are procured & shipped in batches over much longer 4 year period. Begin 2021 – End 2024
- Strategy prepare coated installation-ready M1 segments as they arrived & place in storage – ready for rapid installation
 - > Need:
 - Somewhere to store 798 segment assemblies
 - Mirror coatings as "fresh" as possible at start of science operations
 - M1 components (edge sensors, electronics, cabling, etc.) ready for pre-install



Fresh M1 Coatings

- Problem: coating 798 M1 mirrors takes considerable time
 - Need good M1 coatings at start science operations
 - Solution: pre-coat segments & store in inert environment
 - Protected inside plastic bags in dark & under positive pressure. Nitrogen gas
 - Experience suggest this preserves mirror reflectivity. Need to test

Alternatives were:

- Store uncoated & coat quickly, just-in-time
 - Hurries process. Risks overall schedule if problems or delays
 - Double handling. Need to open M1SS TC twice.
 - Even freshest coatings 1 year + old
- Coat & install M1, as they arrive
 - Oldest coating already ~3 years old at start of science operations
- Pre-coat in Europe. Store & ship as required
 - Same issues as in Paranal. Desert is benign inert environment
 - Degradation during shipping. Risk delays to AIV if shipping delayed.
 - Need to build up operations expertise for re-coating later in more time-critical ops phase



M1 Segment Storage

Store segments outside in M1SS transport container boxes

- > Hermitically sealed inside bags with inert gas fill to preserve coating lifetime
- Small roof to provide sunshade & extra weatherproofing
- Security fence. Earthquake stabilized, stacked two high.
- Segment Storage Yard (SSY) in Paranal
 - > Containers arranged in rows. Access corridors for forklift. Stacked two high.
 - > Boxes 2 x 2 x 1 m. 798 mirror seg = $1600m^2$ footprint, 50 x 140m. long yard







Installing & aligning M1 Segments







M1 Mirror Assemblies Telescope Installation & Alignment

Installation of 798 M1 mirror segments is a major AIV tasks

- Nominal accuracy of telescope M1 cell mounting flanges not sufficient
- Intermediate interfaces (Fixed Frames) installed & aligned using laser tracker technology to higher precision
- Labor intensive task expected to involve 10-12 months of work by multiple teams of technicians. On the critical path for overall EELT schedule

Parallel installation process below in M1 Cell installing:

- Position actuators for M1 segments (3x 798)
- > M1 control system cabling, electronics, power supplies, network, cooling

Installation of coated telescope-ready M1 Mirror Assemblies

- M1 handling process. Lifting system, M1 crane/manipulator
- Tested & verified extensively before use with "live" glass
- Preliminary testing & servo-tuning each installed segment



Telescope Optical Assembly & Alignment

- All major optical sub-units M2-3-4-5 will have been extensively tested off-telescope using dummy mirrors
 - Planned practice installation of each sub-system with dummy mirror

Final steps:

- removal of each sub-unit from telescope
- installation of "real" coated optic in each sub-unit (done in Paranal)
- Re-installation of sub-units in the telescope
- Pre-Focal Stations wavefront sensing installed & tested

E-ELT now becomes a telescope

- > Alignment checks of complete optical system can begin
 - Straightforward process due to previous dimensional verification
- > M1 will evolve partially installed annulus of M1 segments from center out

Completed telescope ready to form image on-sky



On-Sky Testing & Technical Commissioning

- Towards the end of telescope assembly:
 - all coated M2-3-4-5 mirrors have been installed
 - sufficient M1 segments are in place (four rings, 156 segs, 20% M1)
 - EELT achieves "1stStar" on a Test Camera & night-time testing can begin

AIV activities switch to a 24-hour cycle day-night activities

- Daytime activity of continued installation of remaining M1 segments
- Nighttime alignment & phasing of installed M1 segments
- Pre-planned series of on-sky tests, adjustments, tuning & troubleshooting
- Gradually debugging systems & improving performance
- Developing deeper understanding of optimum control strategies & procedures which work best for E-ELT on-sky operations

Technical follow-up in daytime any issues & problems

Problem reporting system, logging data in Engineering Archive, documenting all test results



Instrument AIV



EELT AIV Workshop 14, 23, 24 June, 2016 ESO-286946

S+ E-ELT Instruments MAORY, MICADO, HARMONI & METIS





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Instrument AIV & Installation

- During later stages of telescope integration, instrument teams start arriving at Armazones & begin their work reassembly & integration of their instruments
 - where possible work done 'off-telescope' in Instrument Integration lab
 - lifted as pre-assembled modules, limited by size/capacity of cranes
- Larger EELT instruments (MAORY, HARMONI) will be largely assembled & aligned in-place on Nasmyth Platforms
 - > AIV staff will assist instrument teams with installation, alignment & connection
- All EELT instruments will have undergone extensive systemlevel testing in Europe, prior to arriving at Armazones
 - installed instruments will undergo testing & tuning during daytime
 - night-time on-sky commissioning only after end of technical commissioning & hand-over to science commissioning (*next slide*)



E-ELT AIV Ingredients

PLACES PEOPLE PARTS PROCESS





Verification - the "V" in AIV

- Verification & Validation of E-ELT are important last steps
 - where 'E-ELT' means everything, the telescope, dome, facilities, instruments, as well as operational tools, processes and procedures
- Purpose is to demonstrate systematically through checks, & tests that the E-ELT meets the expectations of the end-users (astronomers and operations) in terms of performance, efficiency and operability
 - Important to make E-ELT available for science as quickly as possible
 - Verification and validation process needs to be efficient and effective, and to target the systems and performance requirements which matter the most
- Overall strategy is to rely as much as possible on selected off-telescope functional testing of sub-systems, followed by more thorough system-level testing as part of the general tuning and debugging process.
 - > Only where strictly necessary will separate on-site verification testing be done
 - Contractual procurement in Europe involves several stages of acceptance testing
 - Checks of individual components in order to reduce the risk of wasted time and effort if faulty components were to be installed on the telescope (e.g. edge sensors, actuators)



Technical vs. Science Commissioning

- Technical Commissioning using Test Camera
 - Under responsibility of <u>AIV Manager</u>
 - Begins when M2-3-4-5 optics installed at 1stStar milestone
 - Ends with Technical 1stLight 798 seg & diffraction-limited Test Camera image

Science Commissioning

- > Under responsibility <u>Programme Scientist</u>. Includes Instrument Commissioning
- Begins at the end of Technical Commissioning 1stLight
- Ends at Hand-Over of EELT telescope & instrumentation to Paranal Operations
- Hand-Over to Operations formal end to EELT Programme
 - Includes SciOps process/procedure commissioning & verification
 - Formal acceptance tests & verification against TLR & Level 1 specs

Science Commissioning



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Delivering E-EELT Ready for Science Commissioning

- Completion of M1 installation and the telescope Technical Commission marks end of AIV
 - EELT will have been demonstrated to deliver (with the Test Camera) diffraction-limited performance with basic AO and laser guide stars
 - responsibility for EELT passes to the Science Commissioning Team

AIV Team provides on-going technical support for:

- Follow-up of technical problems
- Continued tuning & optimization
- Instrument commissioning teams
- Preventive maintenance
- Training & hand-over to Paranal technical operations staff



Conclusions & Challenges Ahead

Considerable effort into the early planning and preparation for the E-ELT AIV phase

Strategy based on previous experience with the VLT & Paranal observatory

- Size, scale, and complexity of E-ELT presents a new level of challenge
- Many new and significant hurdles to overcome:
 - Huge number of M1 components
 - Phasing a 39m.segmented M1 primary mirror
 - Integrated active-AO-LGS E-ELT telescope

With detailed planning and thorough preparation, we believe we can achieve a successful on-time delivery of an E-ELT and instrument suite which is both scientifically productive and meets its ambitious performance goals







