

ACES – the challenges of building a time machine; past, present and future

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ACES PA&S

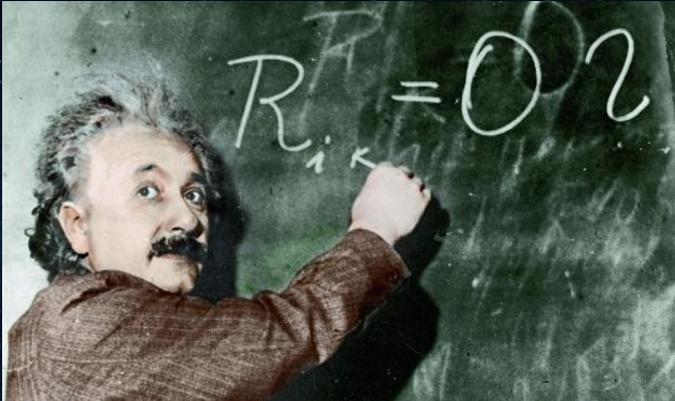
TRISMAC 2024

- What is ACES
- History of ACES
- Recent Project Activities & Current Status
- Conclusions
- Questions

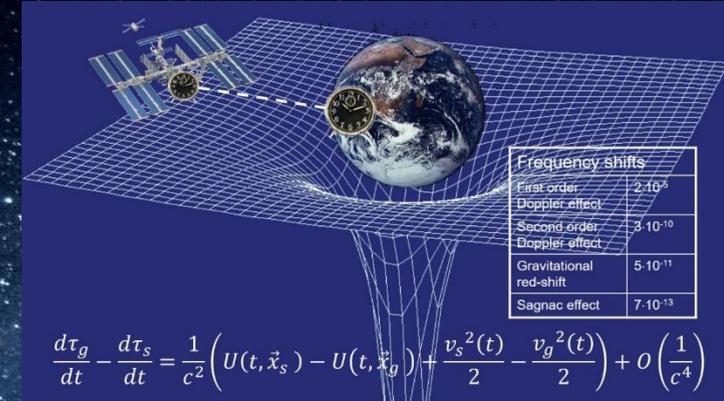
What is ACES?

(Atomic Clock Ensemble in Space)

ACES: Testing the Fundamental Laws of Physics



ACES will be used to test Einstein's theory of general relativity

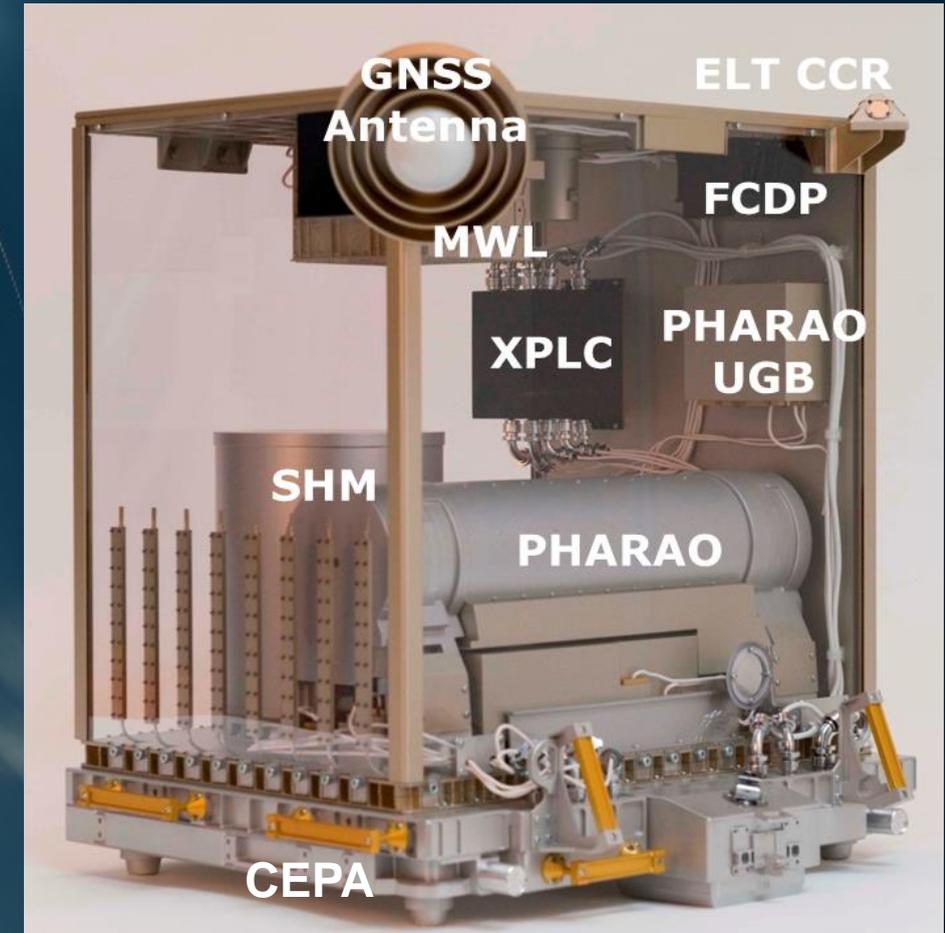


ACES Mission Objectives	ACES Performances	Scientific Background and Recent Results
Measurement of the gravitational red-shift	Absolute measurement of the gravitational red-shift to $< 2 \cdot 10^{-6}$ after 10 days of integration time.	Factor 70 improvement over the Gravity Probe A (GPA) experiment and factor 10 over tests involving Galileo 5 and 6 satellites.
Search for time drifts of fundamental constants	Time variations of α constrained to $\alpha^{-1} \cdot d\alpha/dt < 3 \cdot 10^{-18} \text{ yr}^{-1}$ after 3 years of mission.	α drift constrained to $1 \cdot 10^{-18} \text{ yr}^{-1}$ comparing the electric quadrupole and octupole transitions in $^{171}\text{Yb}^+$. ACES compares clocks based on different atoms on a worldwide scale constraining α , m_e/Λ_{QCD} and m_q/Λ_{QCD} .
Dark matter search with atomic clocks	Establish bounds on topological dark matter models based on the comparisons of clocks in the ACES network.	Comparisons via the ACES network testing different terms in the scalar field model Lagrangian and imposing limits on the three coupling constants Λ_α , Λ_e , and Λ_q . Clock comparisons can be performed continuously on ~ 24 -day intervals thanks to the ACES MWL, thus extending the analysis on the interval T between encounters by one order of magnitude.



ACES Payload: Subsystems

- **PHARAO** (CNES): atomic clock based on laser-cooled Cs atoms
- **SHM**: active Space Hydrogen Maser
- **FCDP**: Frequency Comparison and Distribution Package
- **MWL**: bidirectional Microwave Link, i.e. Time & Frequency (T&F) transfer link, with Ku-band and S-band antennas
- **GNSS** receiver
- **ELT**: European Laser Timing, i.e. optical link, including a Corner Cube Retroreflector (CCR)
- Support subsystems
 - **XPLC**: eXternal Payload Computer
 - **PDU**: Power Distribution Unit
 - Mechanical, thermal subsystems
 - **CEPA**: Columbus External Payload Adapter

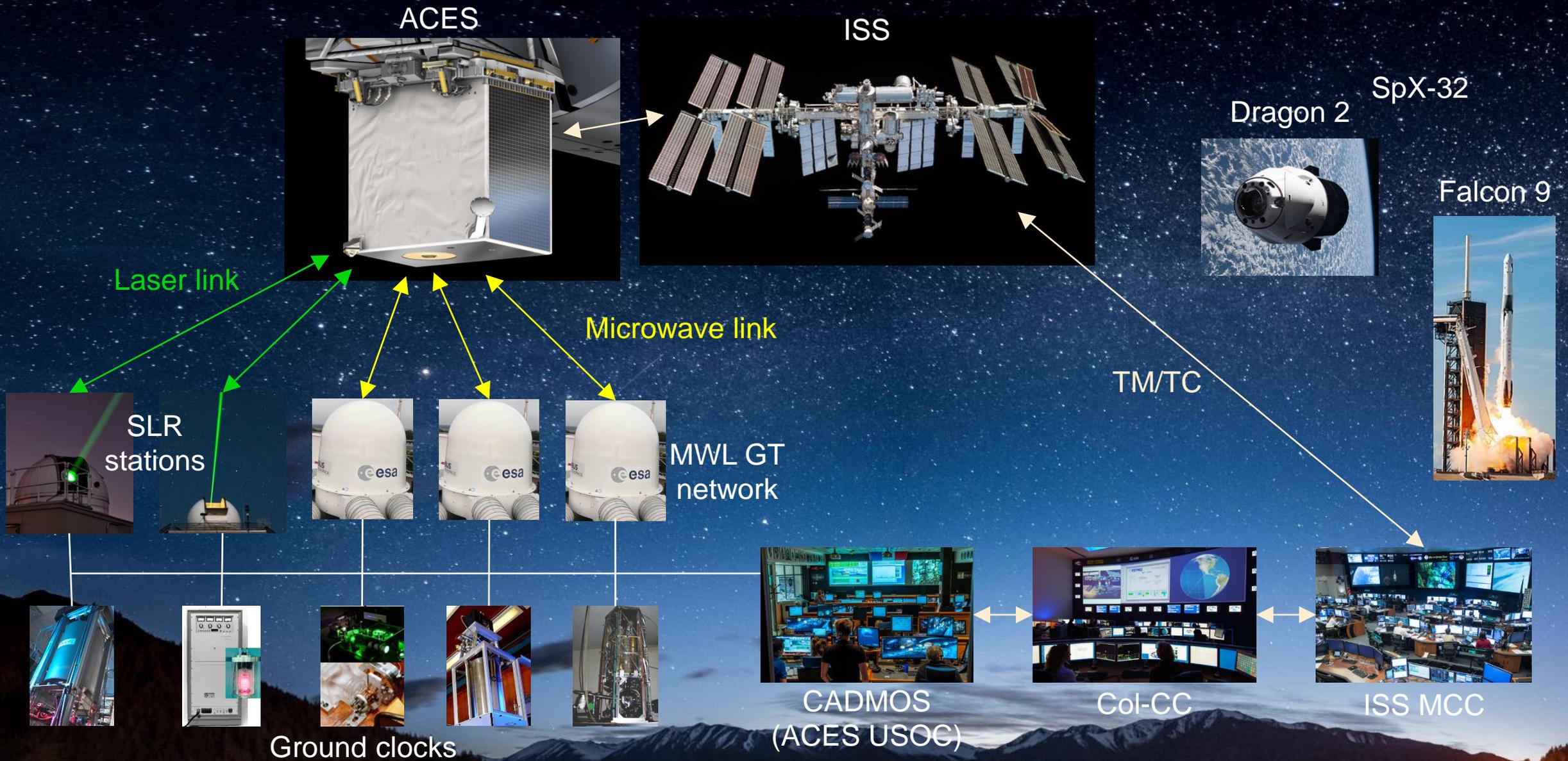


Volume: 1163x867x1153 mm³ (plus ELT CCR and GNSS boom/antenna)
Mass: 249kg plus CEPA (114kg)
Power: 707W (typical)

ISS Columbus Module



ACES Mission Concept



ACES MWL GT Network and Planned Deployment



Systèmes de Référence Temps Espace
SYRTE, Paris, FR (June 2024)

Geodetic Observatory Wettzell,
Wettzell, DE (July 2024)

Physikalisch-Technische Bundesanstalt PTB
Braunschweig, DE (July 2024)

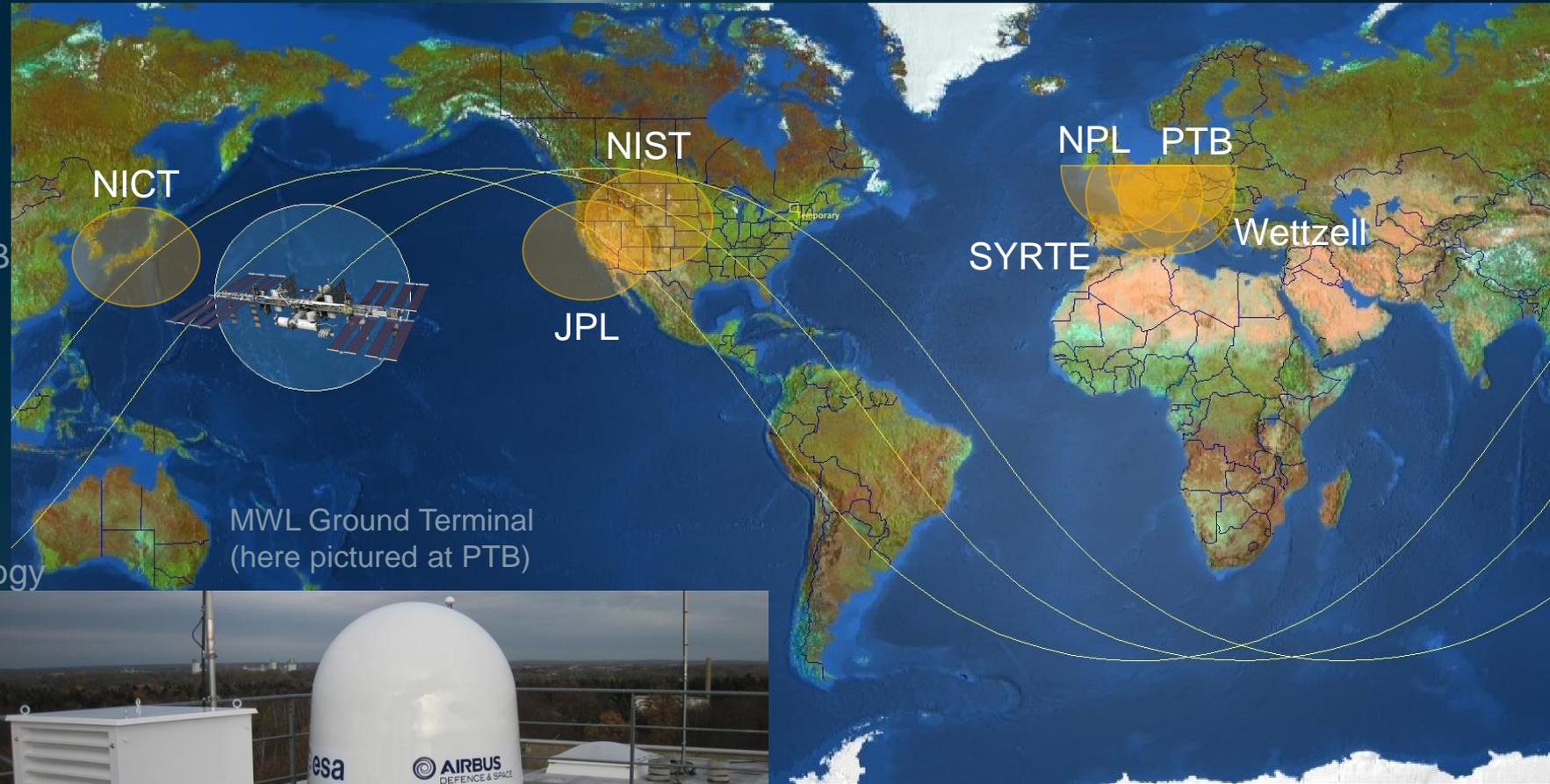
National Physical Laboratory NPL,
Teddington, UK (Aug. 2024)

Jet Propulsion Laboratory JPL,
Pasadena, USA (May 2025)

National Institute of Standards and Technology
NIST, Boulder, USA (June 2025)

National Institute of Information and
Communications Technology NICT,
Tokyo, JP (July 2025)

+ one transportable calibration GT
(June 2024)



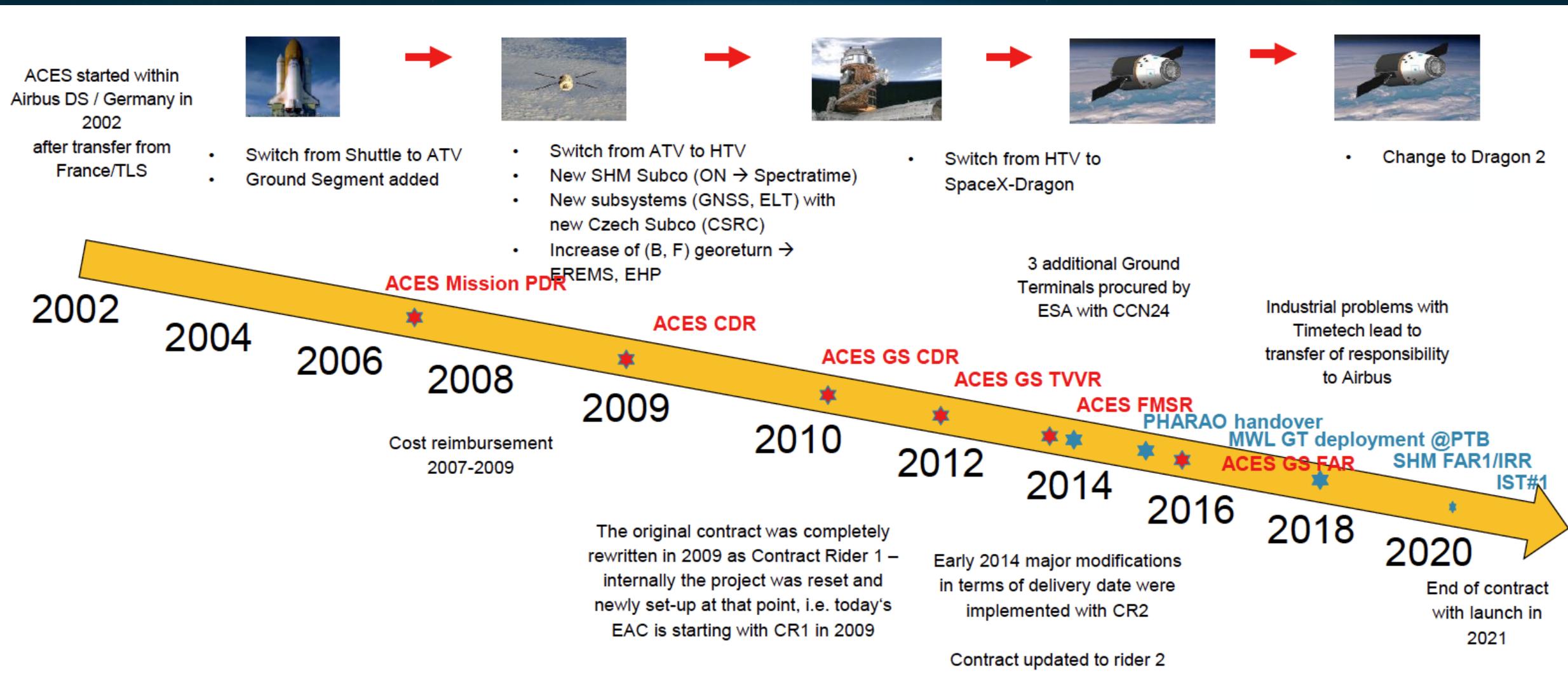
Note: all dates are TBC, the goal is to use all GTs during the in-orbit commissioning



History of ACES



History of ACES



Recent Project Activities & Current Status

CURRENT STATUS 1/3

ACES Independent Review Report - Reference DG-I/2021/963/SM - Issued Jan/Feb 2021

	2020/2021	2024
SHM	<ul style="list-style-type: none"> The acceptance campaign of the SHM was not completed successfully before delivery of SHM for integration in ACES. 	<ul style="list-style-type: none"> Refurbishment of SHM completed → getters replaced Q1 2023 SHM acceptance tested and delivered Q2/Q3 2023 → COMPLETED Integrated into ACES Q3 2023 DRB done Dec 2023 pending final ACT tuning activities with ACES system. 1 open NCR remaining on tuning → for system level
MWL	<ul style="list-style-type: none"> The development of the MWL subsystem is still to be completed, therefore qualification/acceptance activities have not been performed yet. 	<ul style="list-style-type: none"> Q1-Q3 2023 MWL FS refurbished. Replacement of parts agreed and implemented at ADS using a rolling NRB approach → COMPLETED Board level MIPs used to verify delivered status and agree NC recovery activities → Q2-Q4 2023 COMPLETED Final refurbishments and NCR closures Q4 2023 (STM and PRM board oscillators) → COMPLETED SW verification incorporated into equipment VCD and agreed approach/content. → COMPLETED 2024 pending TRB Environmental TRR → COMPLETED 2024 pending TRB

	2020/2021	Dec 2023
FCDP	<ul style="list-style-type: none"> Although testing activities have taken place, the FCDP cannot be considered formally qualified/accepted since several TRBs are still to be closed TVAC test has been moved to system level to allow integration of FCDP in ACES for IST1. 	<ul style="list-style-type: none"> OPEN - Q3 2022 items reduced to 4 NCRs pending ACES IST testing and any associated RFWs → due Q2/Q3 2024
PHARAO	<ul style="list-style-type: none"> PHARAO has been delivered mid-2014 and the 2015 handover review pointed out 6 major items, which, although under control, are not formally closed since the related waivers are still open and should be cleared at system level as soon as possible → Shared ADS/ESA Technical risk 	<p>PHARAO → delivered and integrated Awaiting ACES system level acceptance test</p> <p>CFI under CNES responsibility</p>

Other Equipment:

- Structure/Assembly/Thermal control – Completed
- PDU – Completed/Integrated
- XPLC – Completed/Integrated
- Degaussing Box – Completed/Integrated
- Application SW – Completed
- GNSS - Completed/Integrated
- ELT IU - Completed/Integrated

NCR Burndown and RFW management

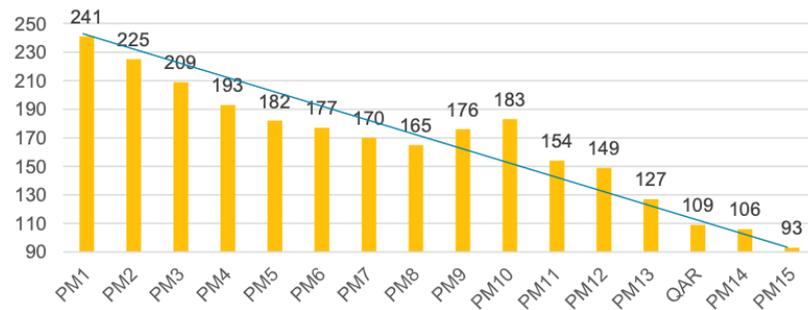
Product Assurance – NCR Status

□ Burndown trend since beg-2022

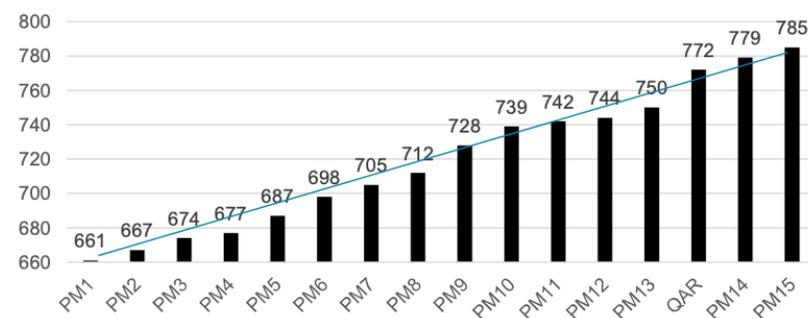
Closed: 272

Created: 124

OPEN NCR



TOTAL NCR

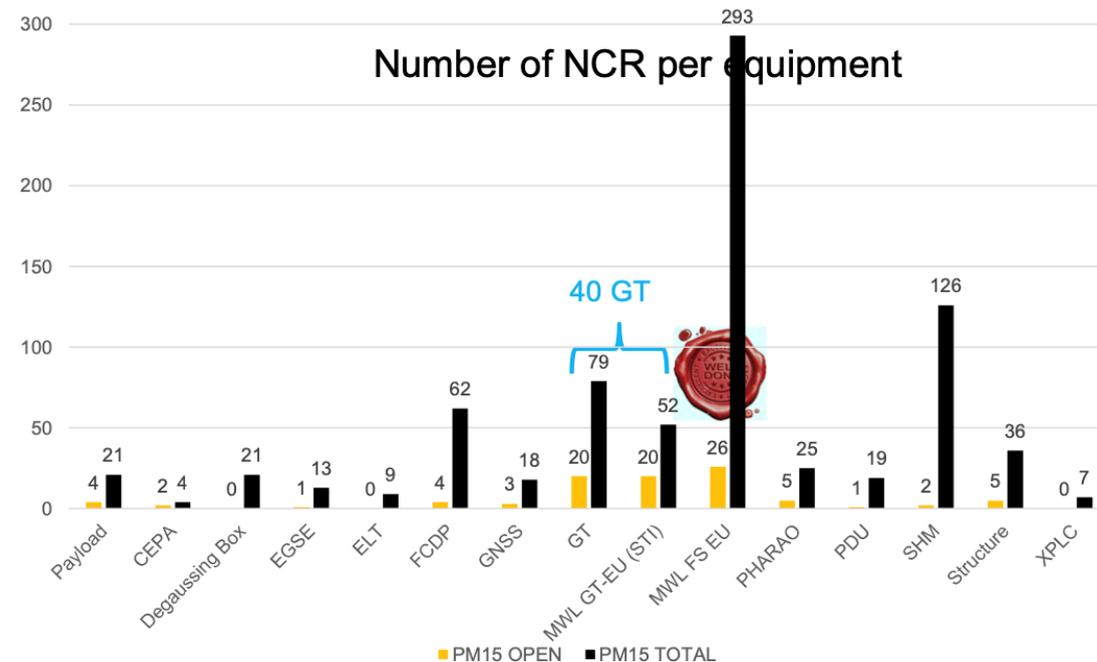


Since last PM

Closed: 18

Created: 6

Number of NCR per equipment

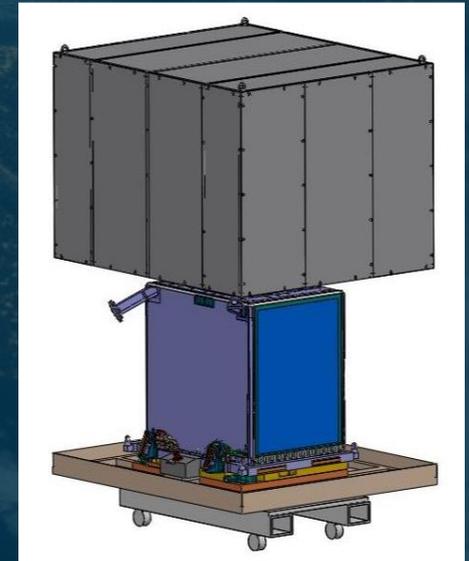
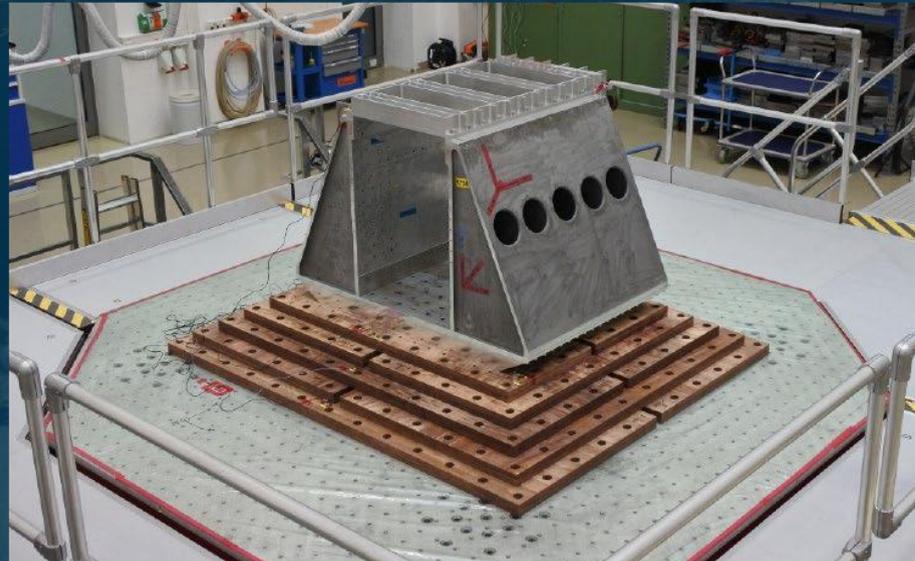
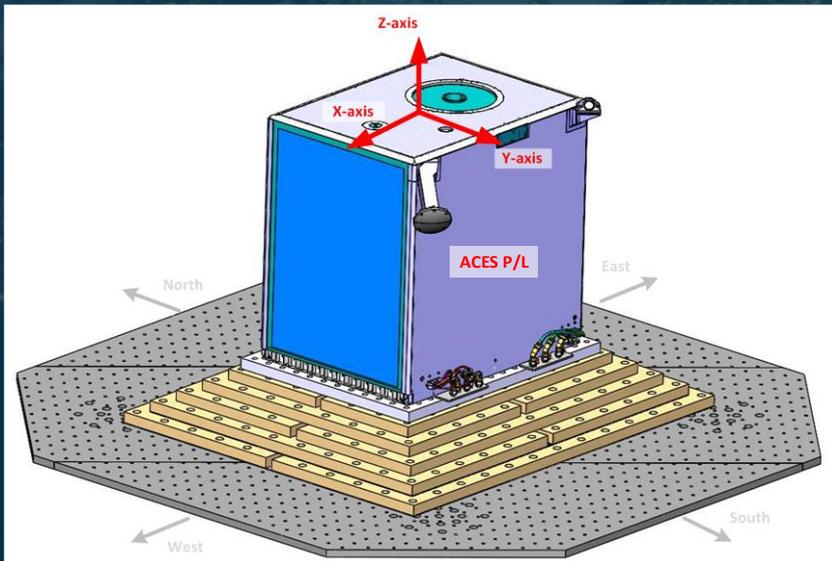


MWL Rolling NRB/refurbishment

- Refurbishment was always intended
- Necessary to replace the EPROMs with PROMs for flight
- Handover of MWL from supplier to Prime was done with many open NCRs and some work that we could not trace via documentation.
- It was agreed as part of the refurbishment activities to perform a board level inspection to cross-check NCR related repairs/rework.
- A large number were identified as either not done/or not done to standard.
- Agreed repair/rework/replacement of components (e.g type II ceramic capacitors) in a Daily meeting
- Established and defined an envelope of processes using ADS FHN existing verification envelope
- Closure of historical NCRs on the basis of final board MIP post refurbishment.
- Needed to consider age of components, age of materials, level of attrition available, risk of failure

ACES: Selected Engineering Challenges

- ACES clocks degrade when exposed to air (negative impact on science)
 - Special Ground Support Equipment (GSE) developed to maintain vacuum locally within SHM
- ACES clocks are extremely sensitive to magnetic fields (non-reversible damages)
 - Special GSE developed to limit magnetic field during vibration testing and transport
 - Magnetic survey needed of all transport phases
 - Potential electromagnetic interference from STP-H10/SPARTA being assessed



SHM Vacuum and Getter lifetime management

SHM Vacuum GSE Pipe Assembly

PROBLEM: Susceptibility of exposure to air seems more critical than expected:

New Manufactured Flight part (elbow)

Y-panel hole cut out by Airbus FHN

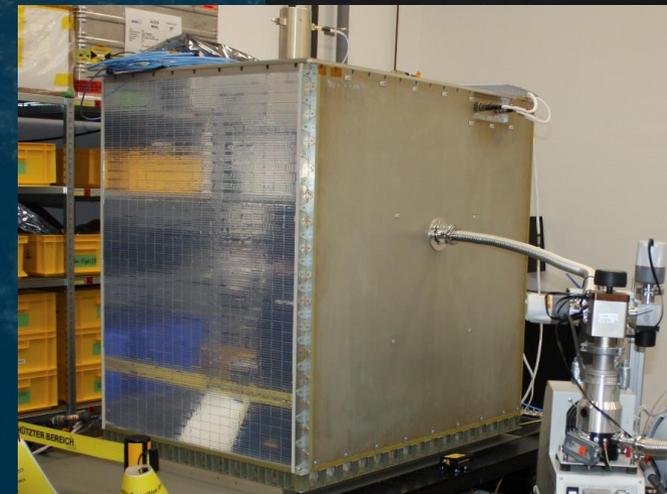
EM assembly for verification done in parallel

Process verification: adhesive bonding of flange

Vacuum level verification

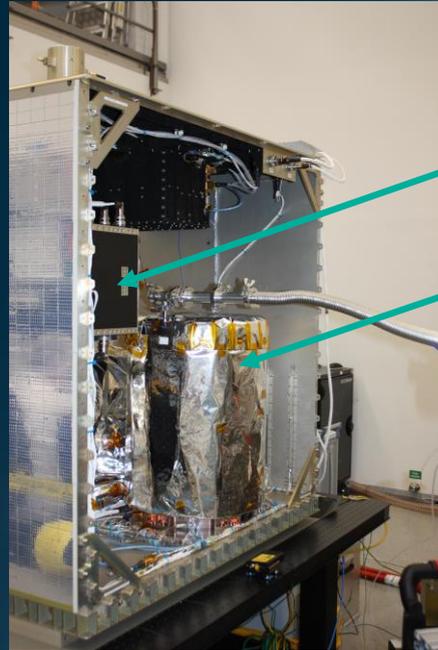
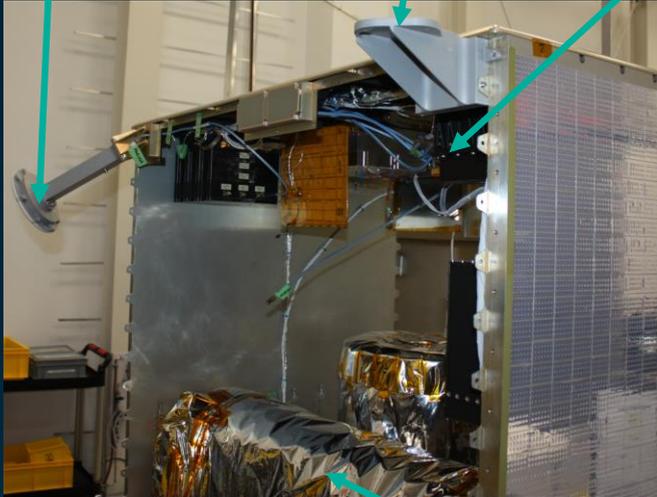
Feasibility test of removing in SPX dragon trunk environment (mock-up built up)

Assembly final integration in ACES PFM May 24



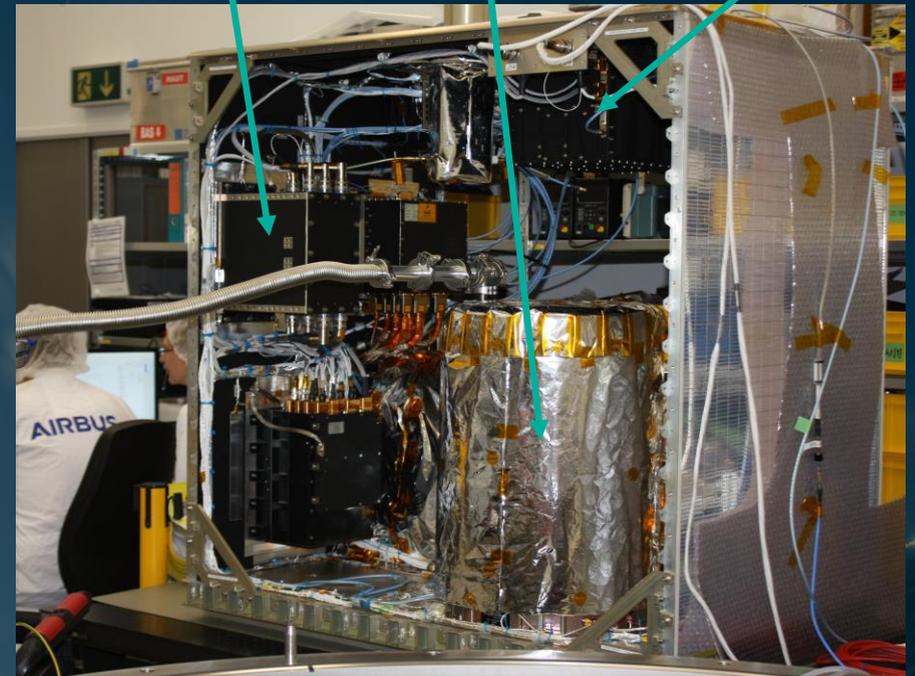
ACES Current Payload activities

GNSS ELT CCR FCDP



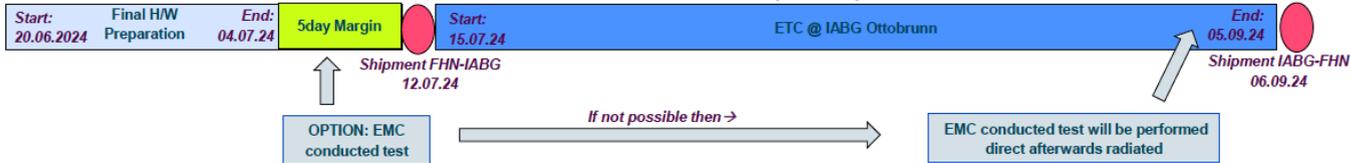
XPLC SHM

MWL



PHARAO

ACES ENVIRONMENTAL TEST CAMPAIGN (ETC):



Way-Forward to the ACES Launch

- Acceptance and flight readiness of ACES
 - ✓ PHARAO, ELT detector, ACES GNSS system, FCDP and refurbished SHM accepted and integrated
 - MWL completed qualification tests and calibration in March 2024
 - MWL acceptance and integration completed April 2024
 - Delta Integrated System Tests (IST) resumed in May 2024
 - ACES-level environmental testing in July-August 2024
 - Final System Verification Tests (SVT) in September-October 2024
 - Joint ESA-NASA Flight Safety Review (FSR) phase III in November 2024
- Shipment from Germany to SSPF as late as possible (around L-7 weeks) to keep ACES under vacuum
- ACES PFM turnover for launch (SpX-32) at L-32 days (currently assuming a launch on 25th Feb, 2025)
- MWL GTs deployment starting this month - June 2024

Conclusions

Conclusions

- ACES has open topics/NCs relating to the performance and acceptance of the PFM.
- Most arise due to the interdependence of the equipments for the experiment and can only be resolved/agreed by the system level tests (IST1b onwards).
- Disposition of performance related NCs has been done anticipating the test output required from the various integrated equipment tests. These mainly are associated with the effect of MWL but some remain with FCDP and SHM.
- Refurbishment activities for the SHM and MWL are COMPLETED and the associated NCs are CLOSED.
- Use of a rolling approach to close-out has become a key part of the final development activities to manage the challenges behind us and ahead of.
- Thanks to the whole PA and PA support team at ADS and ESA.

Produced by

ACES Project Team

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nani gigantum humeris insidentes

*...If I have seen a little further it is by standing on the
shoulders of Giants."*

Sir Isaac Newton, 5th February 1676

