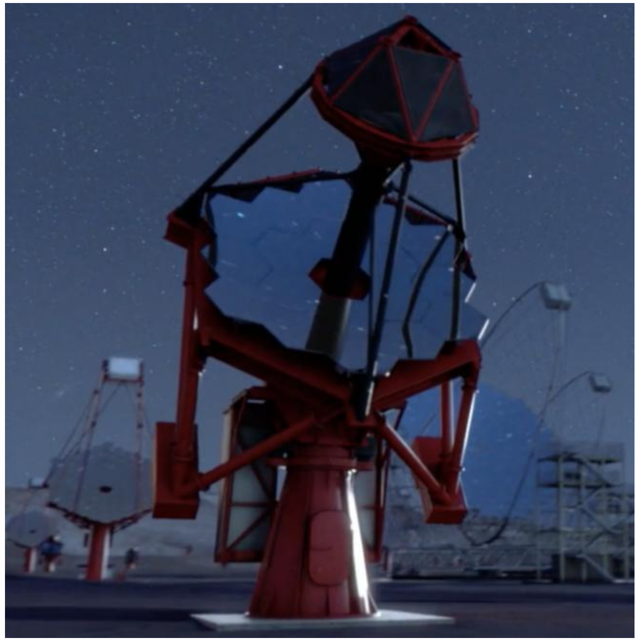
CTAO | SST COLLABORATION

Design, manufacturing, and quality control of the mechanical structures of the Small-Sized Telescopes for CTAO

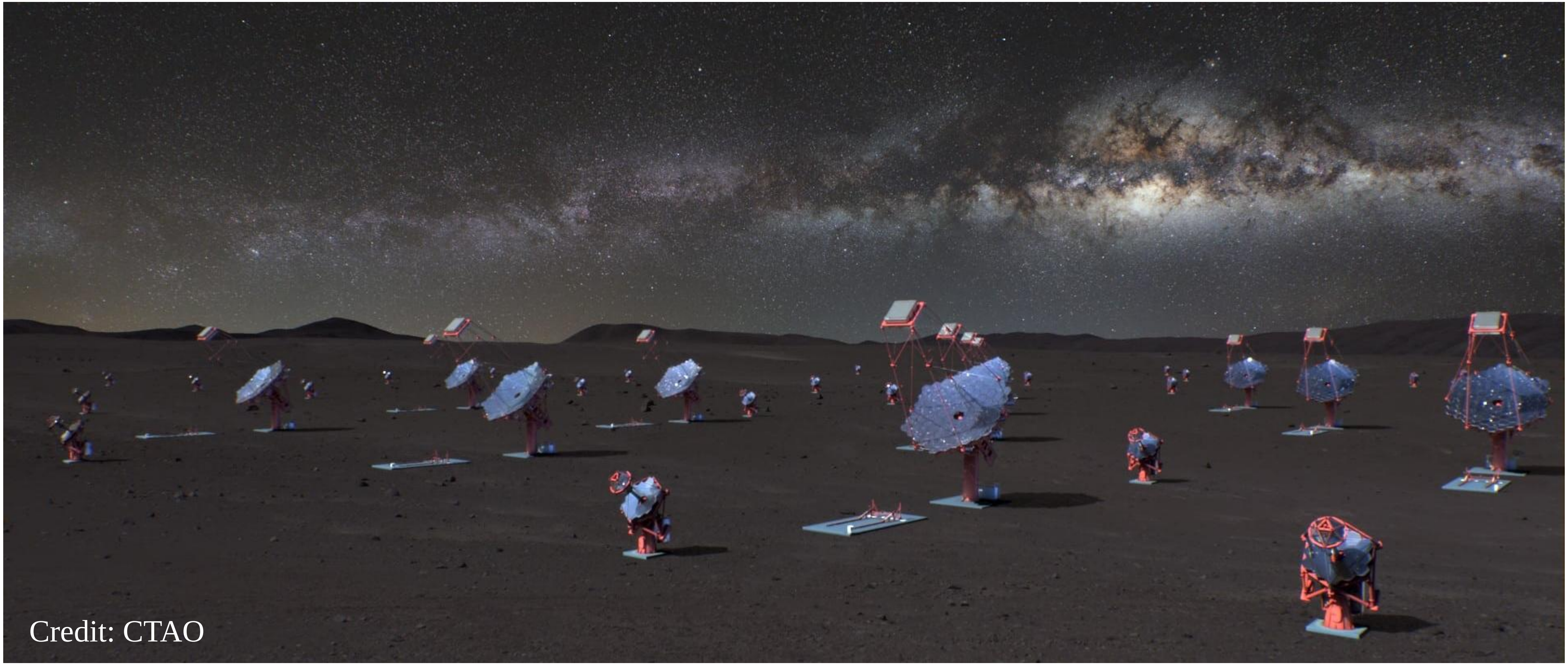
Nicola La Palombara (INAF – IASF Milano)
on behalf of SST WT2



The Cherenkov Telescope Array Observatory

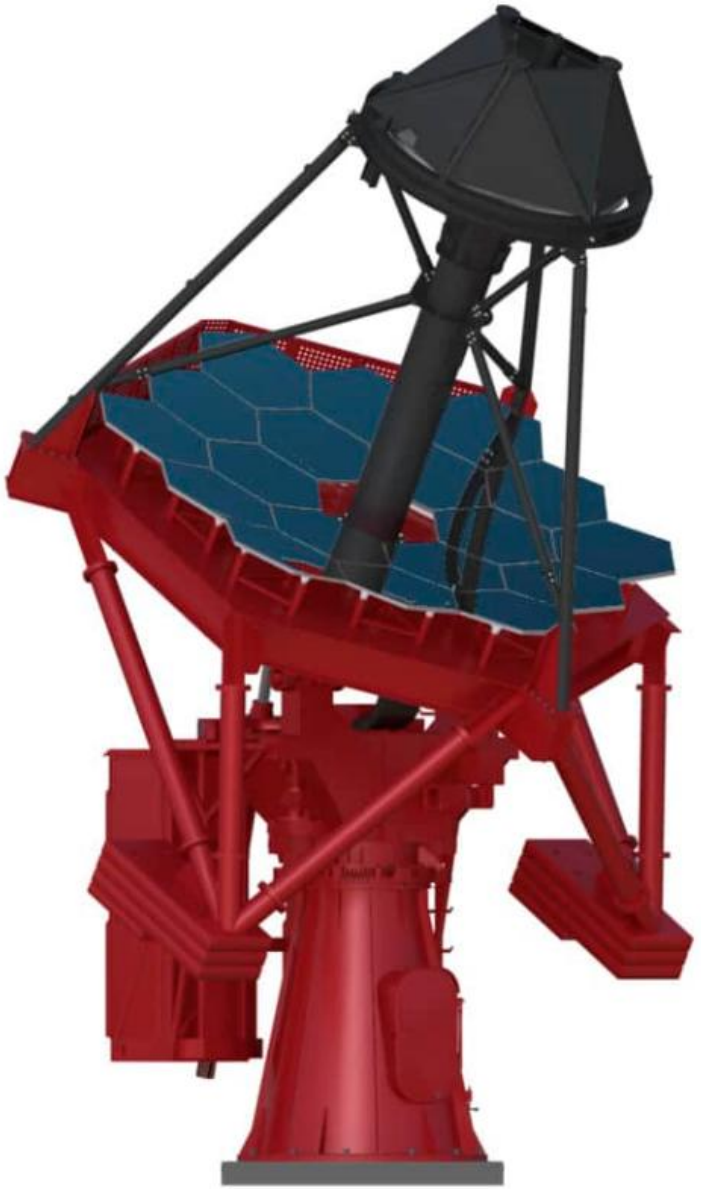
CTAO | SST COLLABORATION

Southern array: 2 LSTs + 14 MSTs + 37 SSTs



The Small-Sized Telescopes (SSTs)

- developed by an international consortium of 22 institutes (from 10 countries), that will provide them as an in-kind contribution to CTAO
- dual-mirror telescopes based on the same concept already applied for the ASTRI Mini-Array @ the Teide Observatory



The Small-Sized Telescopes (SSTs)

CTAO SST COLLABORATION

- validity of the telescope concept and effectiveness of the quality approach adopted for its manufacturing proved by the first results obtained with the ASTRI Mini-Array (see Talks of G. Tosti and S.Vercellone on Monday 20th)
- quality approach even more important in the case of the SSTs, since they shall guarantee the expected performance in spite of two challenging constraints:
  - the expected long lifetime of CTAO (30 years)
  - the hostile environment of the Chile's Atacama Desert

$\Downarrow$

<u>it is essential to perform a strict quality control during the manufacturing activities</u>

A rigorous quality control process was implemented during manufacturing, to ensure compliance with product requirements and to support reliable operation over the telescope's expected 30-year service life in a challenging environment

Design of the mechanical structures

A few changes have been introduced in the design of the SSTs, that take into account not only the experience gained with ASTRI but also the complete different framework:

- the SST telescopes will not be an independent facility but will be part of the CTAO observatory
- the earthquake risk is not negligible
- due to the high number of telescopes (37), the wide area over which they are distributed (~ 10 km^2) and the remote location of the CTAO Southern site (Atacama desert), it will be mandatory to minimize and simplify maintenance activities as much as possible
- the design of the focal plane camera is different from that of the ASTRI one and includes an external chiller

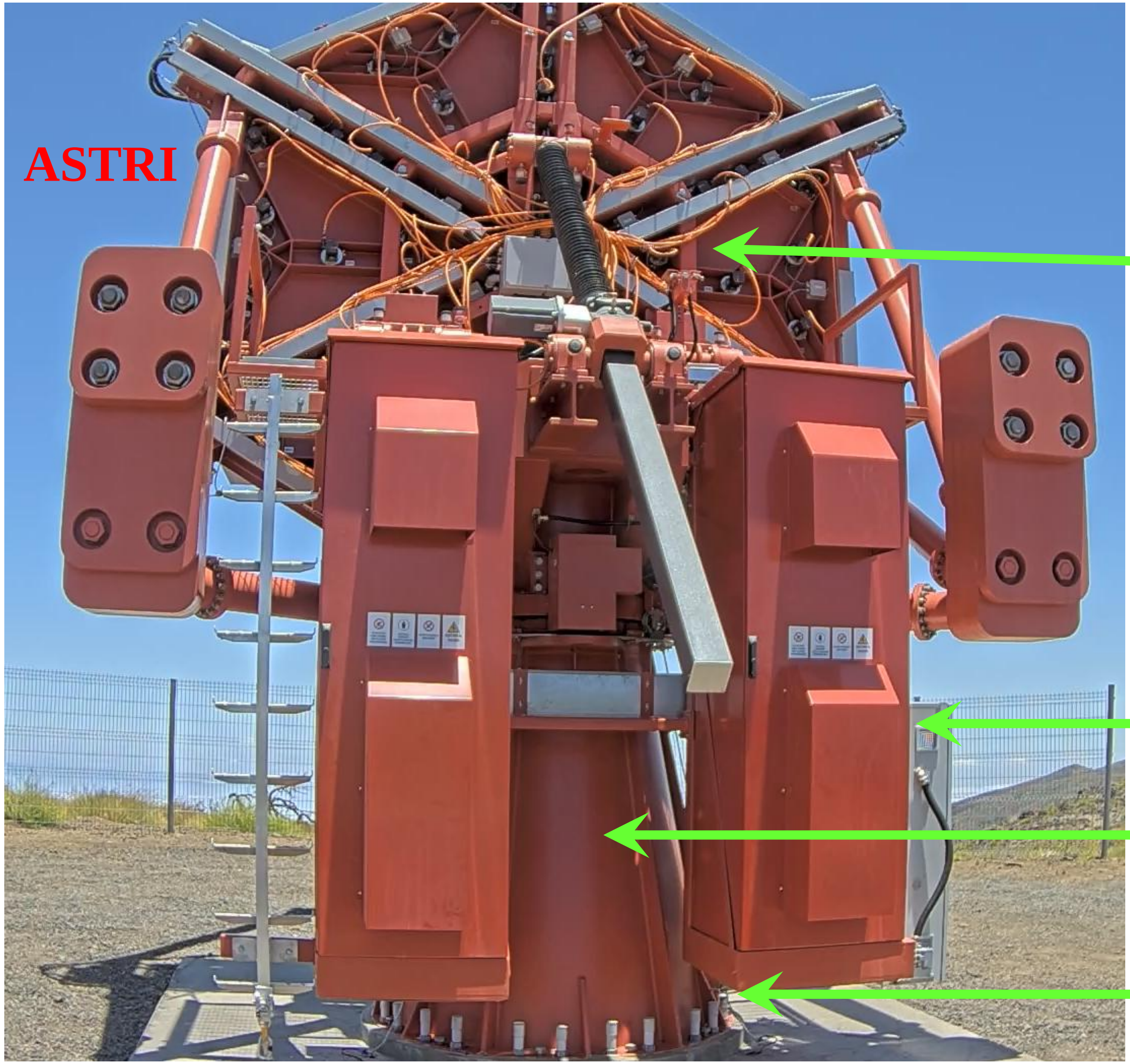
ASTRI-SST comparison

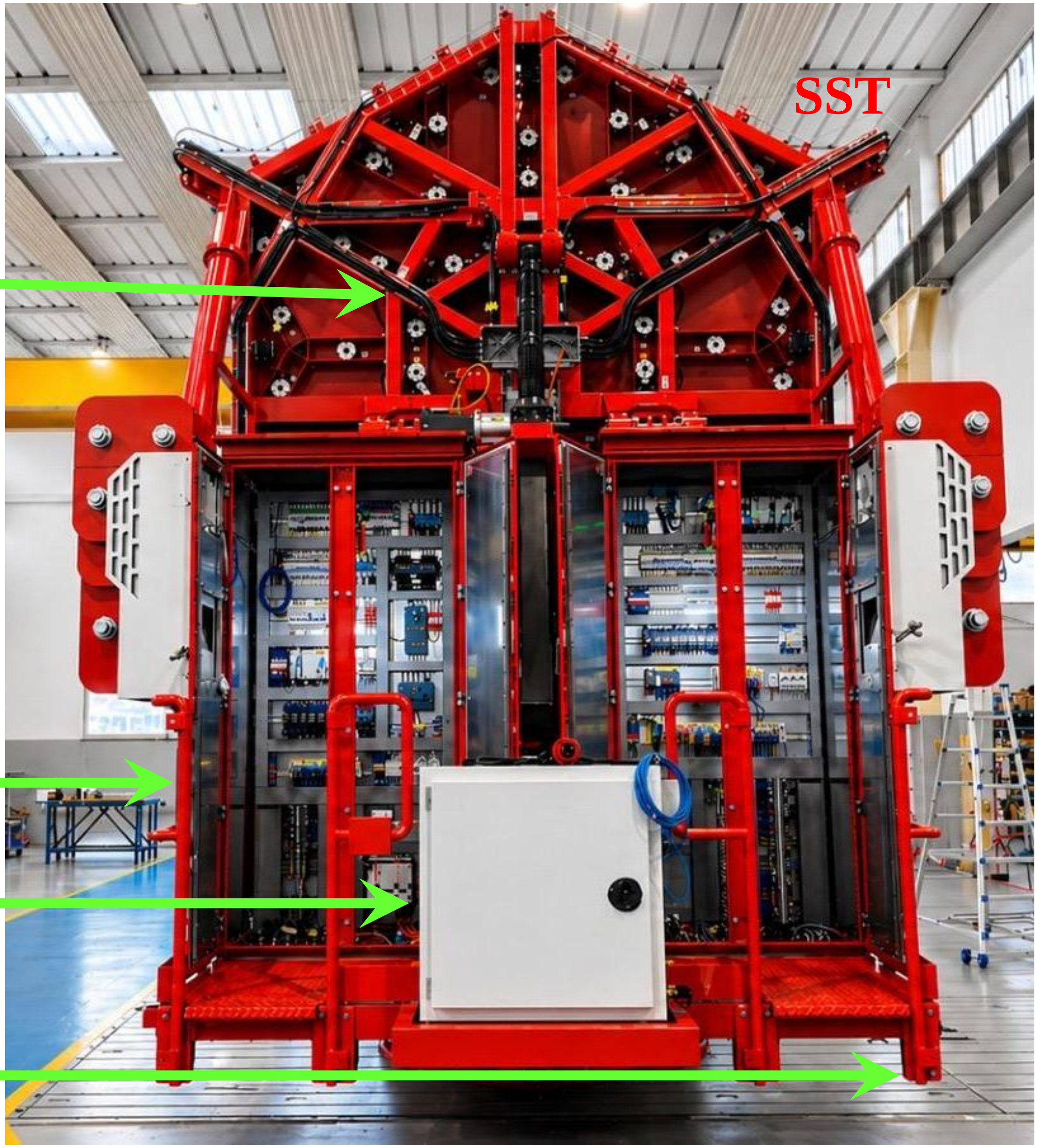
ASTRI

SST

Design of the mechanical structures

CTAO SST COLLABORATION





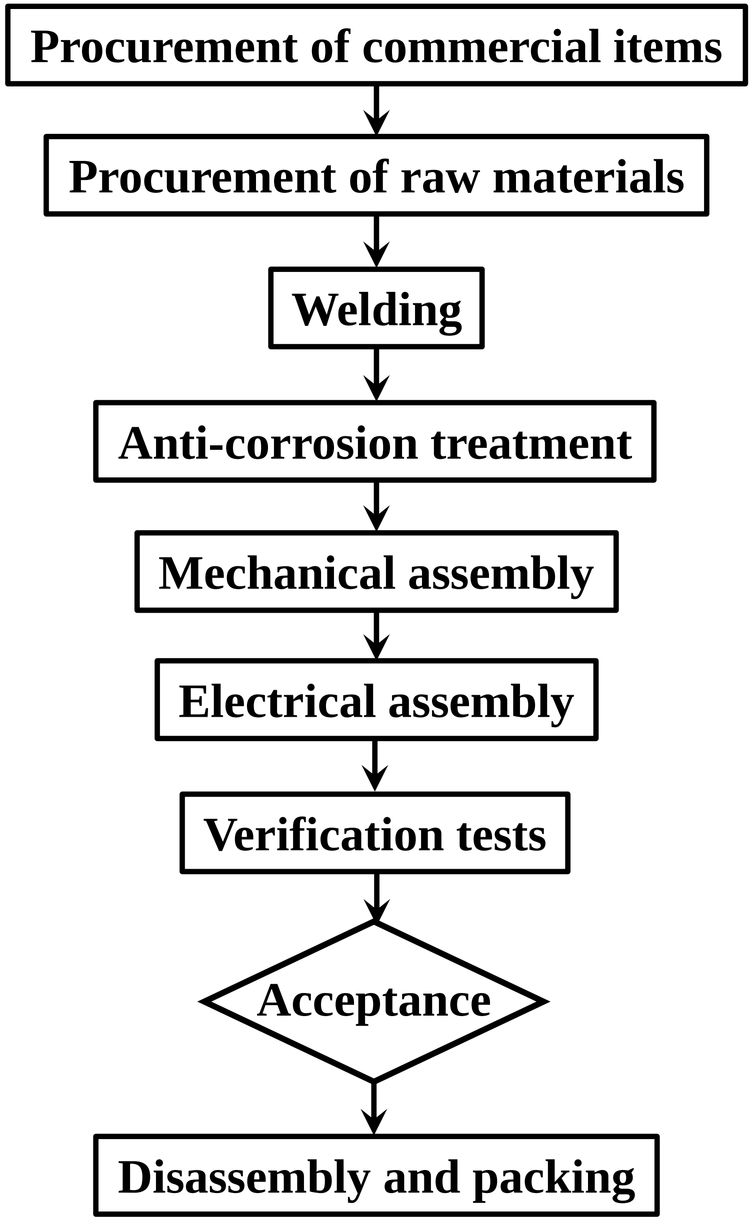
Design of the mechanical structures

The following changes were implemented into the SST design:

- the structure of the M1 dish has been strengthened and stiffened, while maintaining the same weight, thanks to a different pattern of the reinforcement ribs
- both the Telescope Power Cabinet (TPC) and the Telescope Control Cabinet (TCC) have been enlarged, in order to accommodate in a better way all the necessary equipment
- now there is a wide walkable platform, anchored to the Azimuth fork: on one hand, it provides an easier access to the two telescope cabinets; on the other hand, it hosts the camera chiller
- the telescope I/F cabinet, which in the case of ASTRI is located near the telescope foundation, has been eliminated and replaced with an interface point inside the telescope base for the connection with the CTAO services (electrical power, data network, timing control)
- a newly redesigned optimized carter has been implemented, in order to ensure that the internal bearings are sealed against potential external agents
- an automatic lubrication system has been introduced, which, thanks to replaceable lubricant cartridges, provides an effective compromise between the need for consistent lubrication and a low frequency of maintenance interventions
- the configuration of the Azimuth limit switches has been modified, in order to obtain a system that is both simpler and safer compared with that of ASTRI

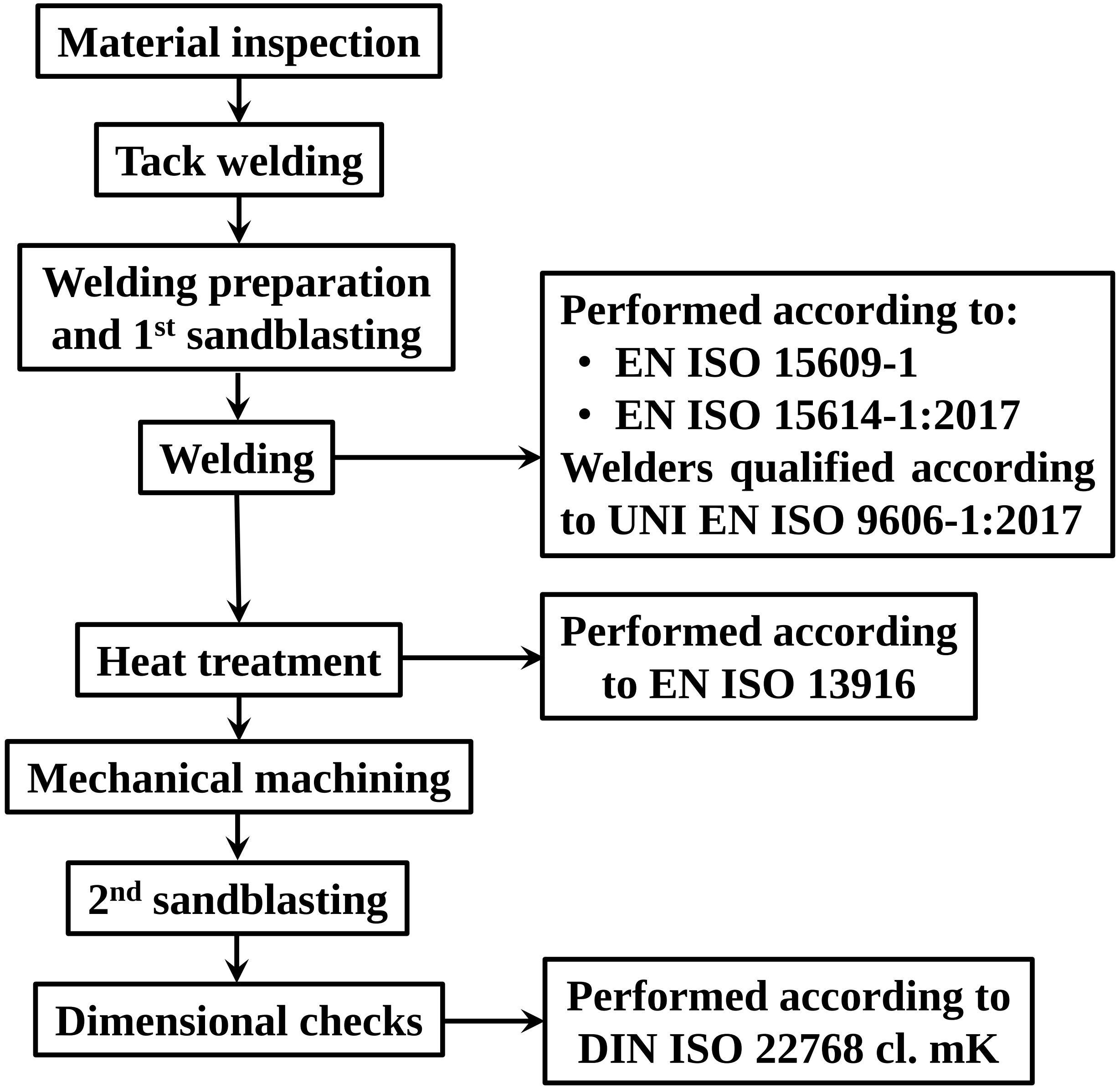
Manufacturing of the SST mechanical structures

Performed by **Dal Ben S.p.A. company** (San Stino di Livenza, Italy) according to a well-defined process, already applied for the ASTRI telescopes



Welding process

A fundamental step in the manufacturing of mechanical items, which needs to be performed by qualified personnel according to certified methods



Welding process

- Inspection of each raw material traced with a Material Inspection Report:
  - material grade, heat number, manufacturer, and mill certificate
  - results of the dimensional and visual checks
  - acceptance/rejection declaration
- Each weld realized following a specific Welding Procedure Specification (WPS), compliant with the standards EN ISO 15609-1 and EN ISO 15614-1:2017
  - compliance of each WPS with the applicable standards proved by a corresponding Welding Process Qualification Record (WPQR)
- All weldings performed by qualified welders, which are periodically trained according to the standard UNI EN ISO 9606-1:2017
  - qualification proven by a Welder Performance Qualification (WPQ)

both WPQRs and WPQs are released by an **independent recognized authority**, such as **IIS** (Istituto Italiano della Saldatura - Italian Institute of Welding) or **RINA** (Registro Italiano Navale - Italian Naval Register)

Anti-corrosion treatment

Surface preparation
(UNI EN 8501-3: corrosion class CX ⇒ preparation grade P3):
1) **Preliminary washing**
2) **Visual inspection**
3) **Full washing with water and solvent**
4) **Rinsing with demineralized water**
5) **BRESLE test (ISO 8502-6/9)**

3rd sandblasting

Final tests before painting:
- **Roughness measurement (ISO 8503-4)**
- **Residual dust test (ISO 8502-3)**

Anti-corrosion treatment:
1) **Application of layer I ⇒ thickness measurement (ISO 19840)**
2) **Application of layer II ⇒ thickness measurement (ISO 19840)**
3) **Application of layer III ⇒ thickness measurement (ISO 19840)**

Surface preparation: BRESLE test

- Aim: to evaluate surface cleanliness and prevent paint adhesion problems due to the presence of contaminants
- Method: measurement of the concentration of soluble salts on metal surfaces, especially steel, before painting, according to the standards ISO 8502-6 and 8502-9
- Procedure: extraction of soluble salts dissolved water and measurement of their concentration via the electrical conductivity of the water

Surface preparation: BRESLE test

1) Patch application: a specific self-adhesive patch is applied to the surface to be tested

Surface preparation: BRESLE test

2) Demineralized Water injection: a predefined amount of demineralized water is injected into the patch

Surface preparation: BRESLE test

3) Salt extraction: the water dissolves the soluble salts present on the surface, creating a solution.

4) Conductivity measurement: a soluble salt tester measures the electrical conductivity of the solution.

5) Determination of soluble salt concentration: the difference in conductivity compared with pure water indicates the concentration of soluble salts present on the surface.

$\Downarrow$

the test is passed if the conductivity difference is < 50 µS/cm

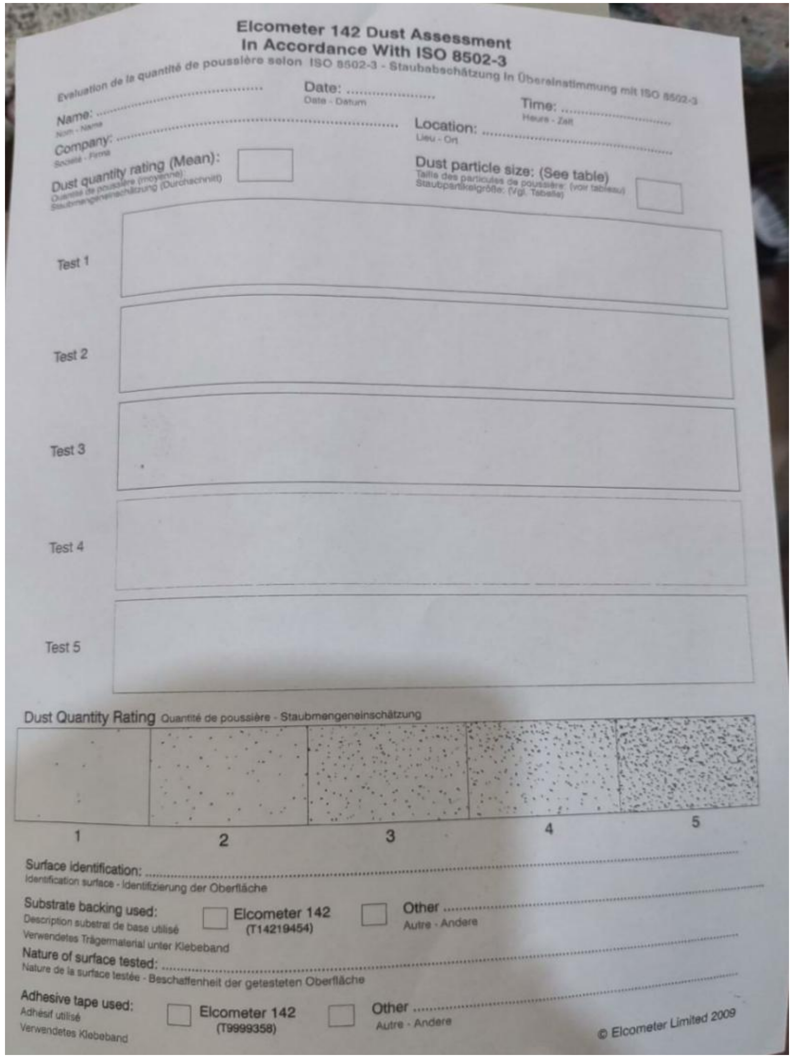
Surface preparation: roughness measurement

Measurement conducted two times, according to the standard ISO 8503-4

Requirement: roughness > 70 µm

Surface preparation: residual dust test

Test performed according to the standard ISO 8502-3, by applying a transparent adhesive tape onto the surface to be verified and comparing the tape with a reference image



Elcometer 142 Dust Assessment
In Accordance With ISO 8502-3
Evaluation de la quantité de poussière selon ISO 8502-3 - Staubabschätzung in Übereinstimmung mit ISO 8502-3

Name: ......
Nom - Name
Date: ......
Date - Datum
Time: ......
Heure - Zeit
Company: ......
Société - Firma
Location: ......
Lieu - Ort
Dust quantity rating (Mean):
Dust particle size: (See table)

Test 1
Test 2
Test 3
Test 4
Test 5

Dust Quantity Rating Quantité de poussière - Staubmengeneinschätzung

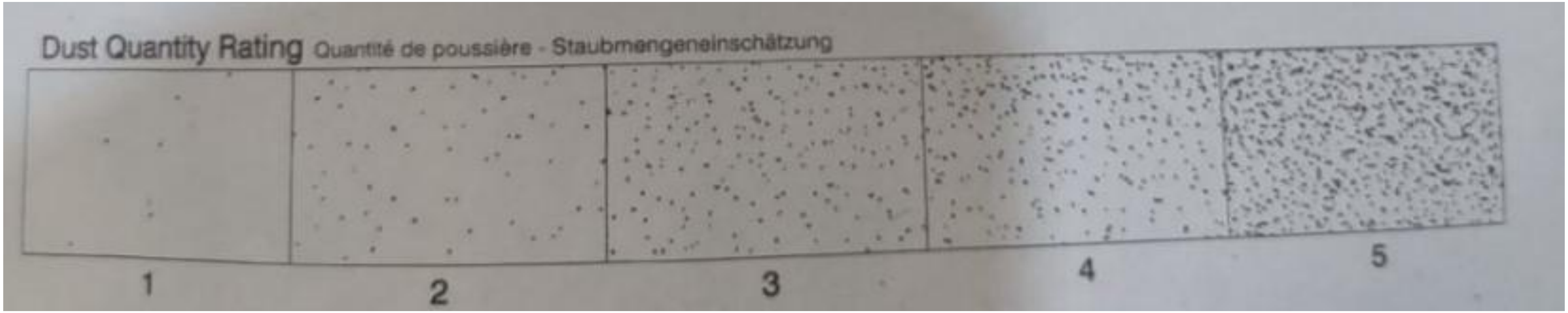
1 2 3 4 5

Surface identification: ......
Identification surface - Identifizierung der Oberfläche
Substrate backing used:
Description substrat de base utilisé
Verwendetes Trägermaterial unter Klebeband
Elcometer 142 (T14219454)
Other ......
Autre - Andere
Nature of surface tested: ......
Nature de la surface testée - Beschaffenheit der getesteten Oberfläche
Adhesive tape used:
Adhésif utilisé
Verwendetes Klebeband
Elcometer 142 (T9999358)
Other ......
Autre - Andere

© Elcometer Limited 2009

Surface preparation: residual dust test

CTAO SST COLLABORATION



Test performed according to the standard ISO 8502-3, by applying a transparent adhesive tape onto the surface to be verified and comparing the tape with a reference image

- quality rating = 1 or 2 ⇒ test passed
- quality rating = 3 ⇒ surface cleaning recommended
- quality rating = 4 or 5 ⇒ surface cleaning mandatory

Surface painting

Painting performed in 3 steps:

1) application of layer I (60 μm of epoxy primer)
   ⇒ thickness measurement (ISO 19840)
2) application of layer II (140 μm of epoxy intermediate)
   ⇒ thickness measurement (ISO 19840)
3) application of layer III (80 μm of silicone acrylic)
   ⇒ thickness measurement (ISO 19840)

Quality Control Plan (QCP)

Tool set up by Dal Ben company to monitor the various phases of the telescope production and to keep a constant and effective quality control of the manufacturing process

$\Downarrow$

a <u>Quality Control matrix</u> that, for each item to be realized
(identified with the corresponding drawing code),
reports the <u>quality analyses, treatments and tests to be performed</u>

Quality Control Plan (QCP)

DESCRIPTION DESCRIZIONE	QUANTITY QUANTITÀ	CHEMICAL ANALYSIS ANALISI CHIMICA	MECHANICAL CHARACTERISTICS CARATTERISTICHE MECCANICHE	HEAT TREATMENT TRATTAMENTO TERMICO	STRESS RELIEVING (P.W.H.T.) DISTENSIONE	N.D.T. VISUAL TEST C.N.D. VISIVO	N.D.T. MAGNETOSCOPIC TEST C.N.D. MAGNETOSCOPICO	N.D.T. DYE PENETRANT TEST C.N.D. LIQUIDI PENETRANTI	N.D.T. ULTRASONIC TEST C.N.D. ULTRASUONI	LEAK TEST PROVA DI TENUTA	DIMENSIONAL REPORT REPORT DIMENSIONALE	W.P.S. & W.P.Q.R.	WELDING MAP MAPPA DI SALDATURA	BALANCING BILANCIATURA	CORROSION PROTECTION PROTEZIONE ANTI-CORROSIONE	COMPLIANCE CERTIFICATE REPORT DI CORRETTO MONTAGGIO	NOTIFICATION NOTE
BASE CARPENTRY	1	X	X		X	X	X				X	X	X		X		
BASE DOOR THREADED ROD	1	X	X														
BASE DOOR STRUCTURE	1					X											
AZ ENCODER HEAD SUPPORT	4	X	X														
AZ ENCODER HEAD PLATE	4	X	X														
AZ ENCODER HEAD PLATE UPPER	4	X	X														
AZ FORK MAIN STRUCTURE	1	X	X		X	X	X		X		X	X	X		X		
AZ FORK SPECIAL KEY	2	X	X														
CABINET SUPPORT R STRUCTURE	1	X	X		X	X	X					X	X				
CABINET SUPPORT L STRUCTURE	1	X	X		X	X	X					X	X				
ADDICTIONAL R STRUCTURE	1	X	X			X	X										
ADDICTIONAL L STRUCTURE	1	X	X			X	X										

Welds verification

Correct execution of all weldings verified through four different types of non-destructive tests (NDTs):

- Visual Test (VT)
- Magnetoscopic Test (MT)
- Penetrant Liquid Test (PLT)
- Ultrasonic Test (UT)

All examinations performed by operators qualified according to the standard EN ISO 9712

Welds verification

Visual Test (UNI EN 17637 and UNI EN 13018):

A non-destructive testing method used to inspect welds and surfaces through appropriate lighting and direct observation, to detect visible defects such as cracks, surface irregularities, or poor workmanship.

$\Downarrow$

the most common NDT, applicable to all types of welding materials, geometries, and processes

- although formally required only for carbon-steel items, in several cases performed by Dal Ben company also for stainless-steel items.
- performed on 100 % of the surface, with a luminosity > 500 LUX
- acceptance criteria defined in UNI EN 5817 CL. C

Welds verification

Magnetoscopic Test (UNI EN 17638):

Use of magnetic fields to detect surface and near-surface defects in ferromagnetic materials (such as carbon steel or ferritic stainless steel)

- when a metal part is magnetized, the magnetic field flows through it
- if there is a crack or flaw, the magnetic field leaks out at that spot

- a surface test usually performed on ~ 25 % of the surface
- acceptance criteria defined in UNI EN 23278 CL. 2
- Use of two different colored developers:
  1) spraying the surface with a white developer, to cover the entire surface and facilitate the visual inspection
  2) spraying the same surface with a black spray, so that the fine iron particles build up in the areas of the leakage and penetrate easily into the defects, to make them easier to see

Welds verification

Magnetoscopic Test (UNI EN 17638):

Welds verification

<u>Penetrant Liquid Test (UNI EN 3452-1)</u>:

Foreseen in two different cases:

- on austenitic stainless steel, where no MT is feasible
- on carbon steel, where for the geometry it is not possible to execute the MT

- usually performed on ~ 25 % of the surface
- acceptance criteria defined in UNI EN 23277 CL. 2
- executed in 4 different steps:
  - weld cleaning with a detergent
  - deposition of a red liquid on the weld
  - after ~ 15 min, weld cleaning with a soft cloth and water
  - deposition of a white liquid on the weld, which highlights possible weld defects

Welds verification

Penetrant Liquid Test (UNI EN 3452-1):

Welds verification

Ultrasonic Test:

The most difficult NDT to be executed

- necessary to obtain a volumetric control of the weld
- mandatory for full-penetration welding, optional for partial-penetration welding

- can be performed with 3 different penetration angles (45°, 60°, and 70°)
- can be performed at 2 different frequencies (2 MHz and 4 MHz):
  - measurements performed at 2 MHz go deeper into the weld but are less precise than measurements executed at 4 MHz

Painting verification

Two different types of destructive tests executed to evaluate the outcome of the painting process:

- pull-off test
- cross-adhesion test

Both types of examinations performed by qualified operators

Painting verification

<u>Pull-off test (ISO 16276-1)</u>:

Test performed:

- on witness sample plates (dimension 300x300x5 mm)
- marked for identification and painted together with each item to be tested

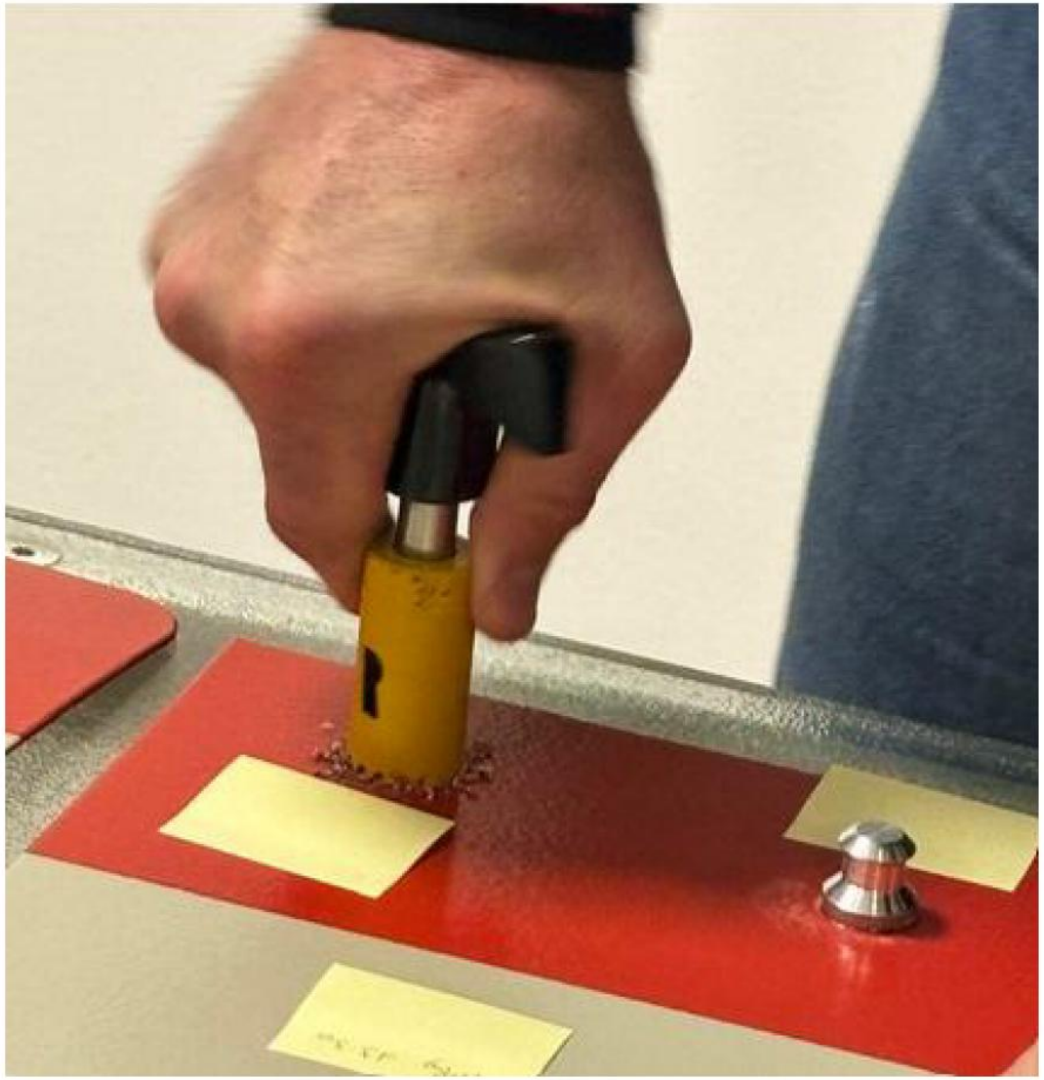
  - test executed when coating is completely dry and fully cured (minimum 10 days after the painting)
  - one sample plate for each production lot

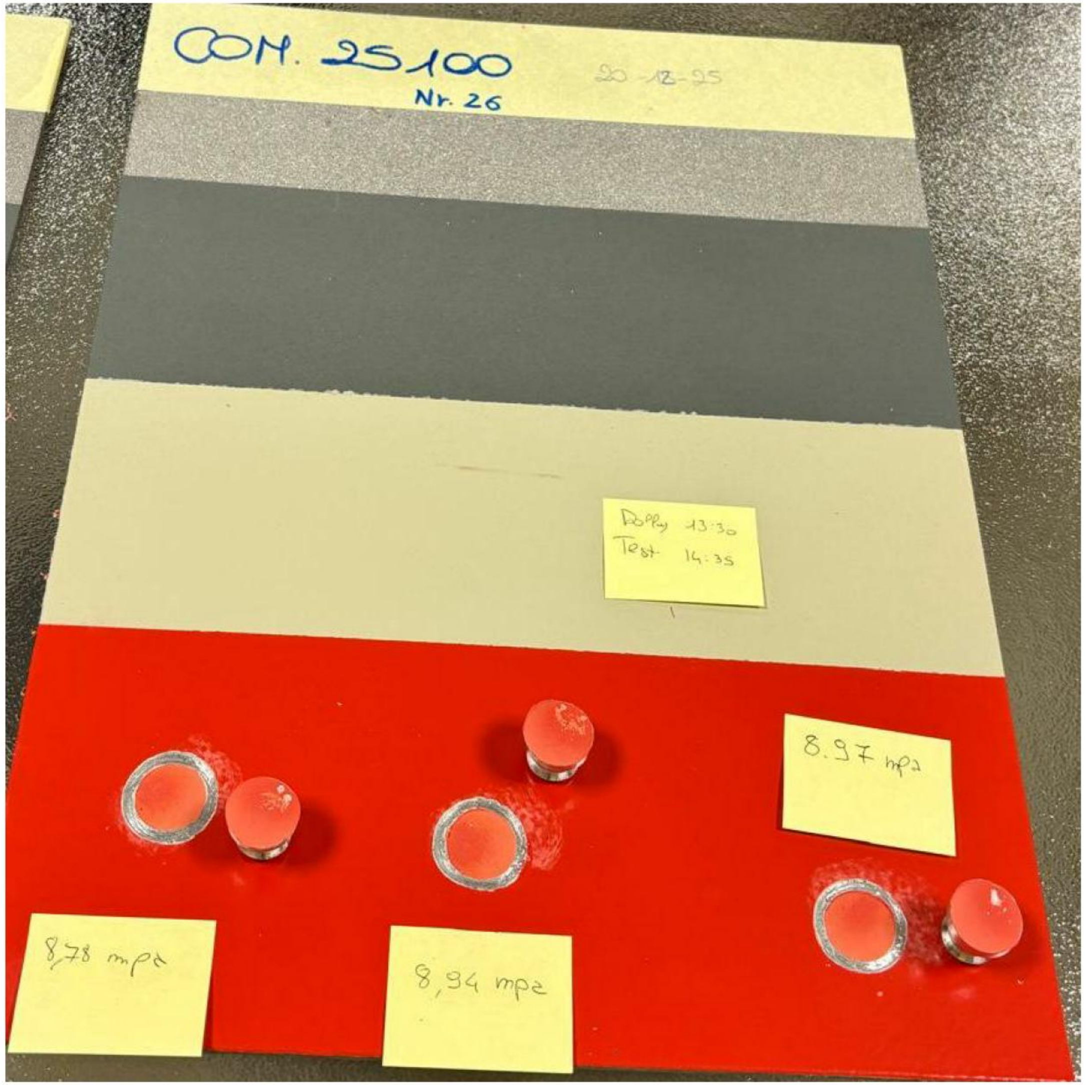
Test performed in three different steps:

- test dollies (pads) are glued in the painted surface
- a cut is executed through the coating layers down to the substrate around the dolly, to avoid lateral stress effects
- a pull-off force is applied until the dollies are detached from the surface itself

Painting verification

<u>Pull-off test (ISO 16276-1)</u>: Test passed if the measured adhesion value is above 3 MPa

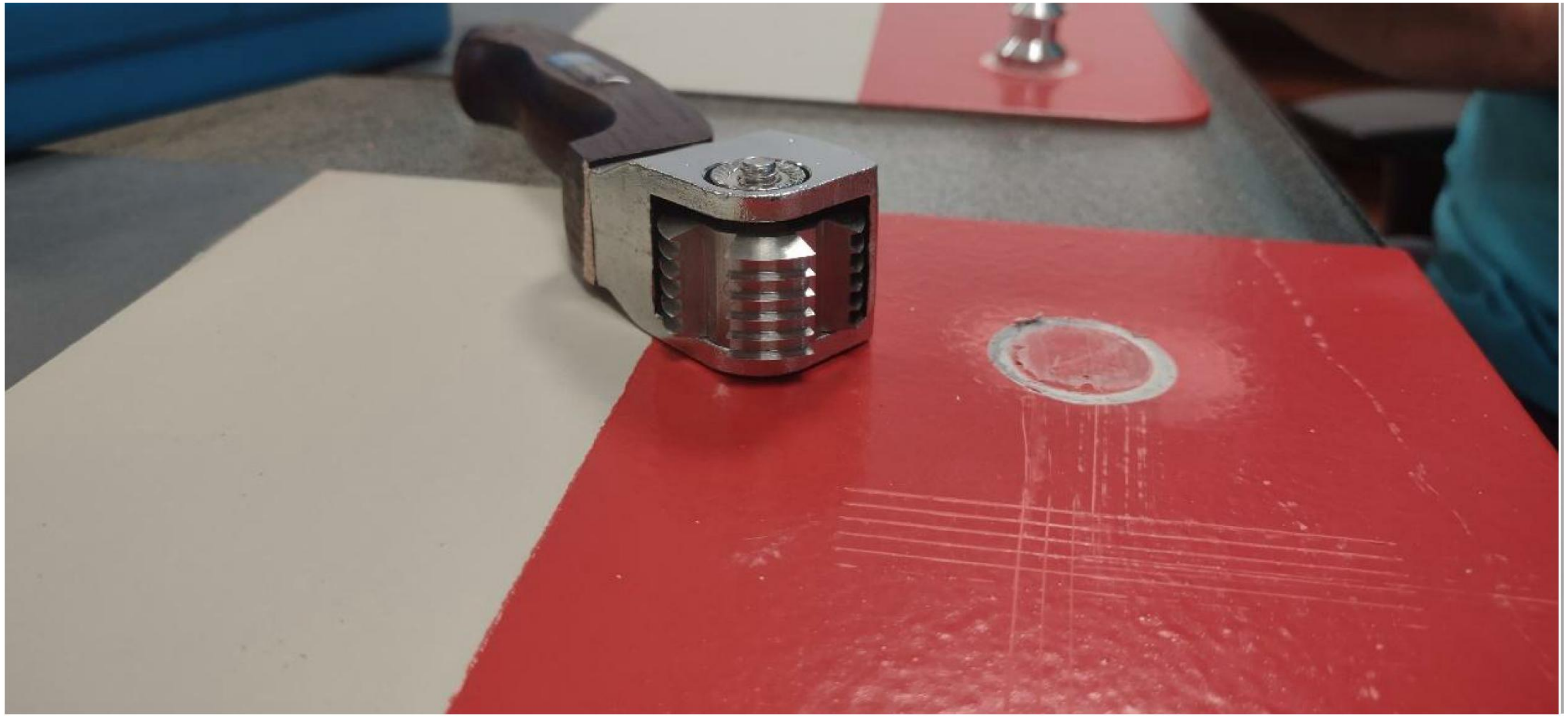




Painting verification

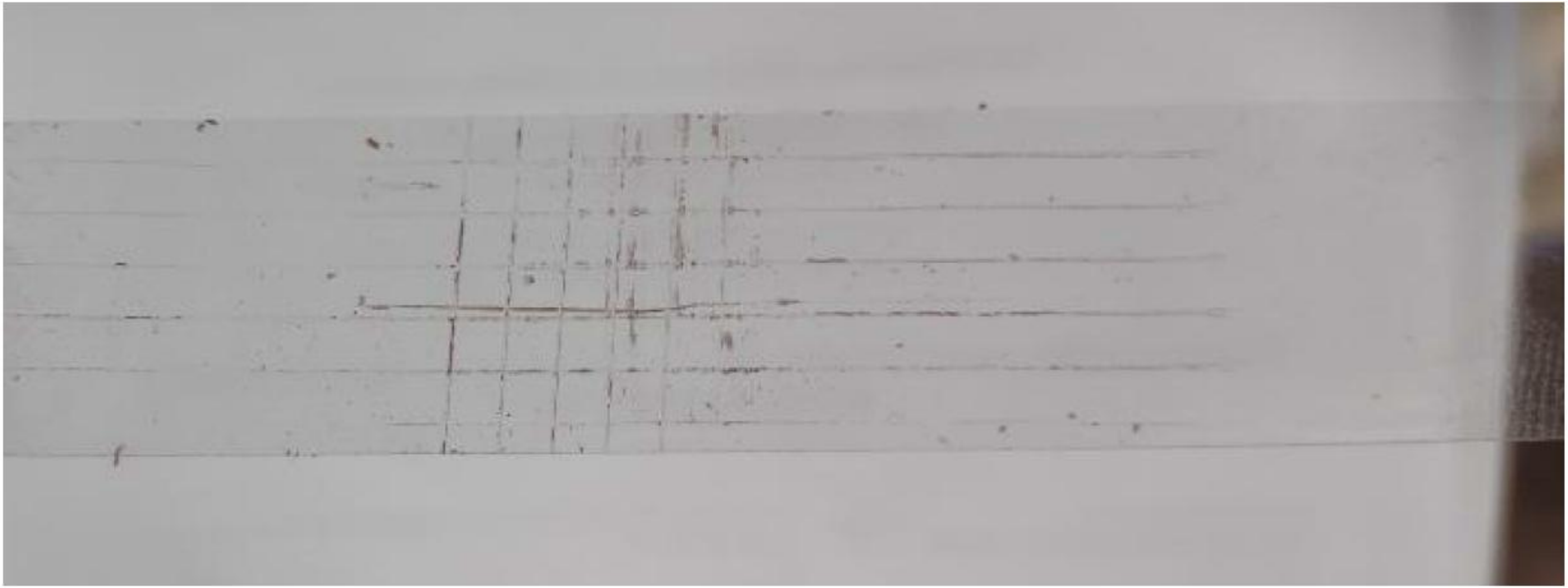
<u>Cross-adhesion test (UNI EN ISO 2409)</u>:

- painted witness sample engraved with two perpendicular sets of parallel straight lines
- a transparent adhesive tape first applied onto the engraved area and then removed from it
- visual check of the residual pattern on the tape



Painting verification

<u>Cross-adhesion test (UNI EN ISO 2409)</u>:



test successfully passed if there are no traces of residual painting in the square areas delimited by the parallel and perpendicular lines

Quality Book

Document that traces in detail the <u>manufacturing history</u> of the telescope itself:

- properties of the raw materials used
- certificates of the manufacturing processes
- reports of the quality inspections and tests

$\Downarrow$

the Quality Book proves that the mechanical structure was realized according to the applicable quality standards

Quality Book

- **QCP (Quality Control Plan)**: list of the inspections and reports to be performed on single parts, divided by drawing code.
- **MIR (Material Inspection Report):** certificates of the raw material used in all the phases of the telescope construction, divided by cutting list and drawing code.
- **Annealing Heat treatment certificates:** reports of stress relieving heat treatment with the hourly/temperature graph.
- **NDTs (Non Destructive Tests) on welds:**
  - VT (Visual Tests)
  - MT (Magnetoscopic Tests)
  - PLT (Penetrant Liquid Tests)
  - UT (Ultrasonic Test)
- **Dimensional reports:** measurements performed during and after machining

Quality Book

- **Welding Book**, including:
  - Welding ID: each weld is coded with a unique progressive position
  - With reference to each position:
    - ✓ WPS (Welding Procedure Specification)
    - ✓ WPQR (Welding Procedure Qualification Record)
    - ✓ WPQ (Welder Performance Qualification)
- **Anti-corrosion protection**, including:
  - painting cycle report
  - painting procedure instruction
  - environmental corrosion class (e.g. CX) reference
  - destructive tests reports
- **Electrical on Factory bench tests**, to ensure the correct installation, wiring and functionality of the electrical and electronical components
- **Tightening torque report**, including tightening maps of the sub-assemblies

Summary and conclusions

- the manufacturing procedures and the quality verifications adopted for the manufacturing of the SST structures are aligned with the recognized international standards, as certified by independent authorities
- the personnel in charge to apply these procedures is qualified by independent authorities, which ensure its expertise
- the Quality Control Plan defines a comprehensive and detailed scheme of the measures, inspections and tests to be executed
- the Quality Book provides full traceability of the performed machining and of the applied controls

$\Downarrow$

the manufacturing process of the SST mechanical structures is fully under control

Summary and conclusions

CTAO SST COLLABORATION

In May the first telescope (**SST #1**) successfully passed the Pre-Shipment Review and CTAO authorized its shipment to the Southern site in Chile, where it will be integrated and tested during Fall 2026

Summary and conclusions

In May the first telescope (**SST #1**) successfully passed the Pre-Shipment Review and CTAO authorized its shipment to the Southern site in Chile, where it will be integrated and tested during Fall 2026

Thanks for your attention!

Back-up slides

Anti-corrosion treatment

SST requirement: “all materials used in the construction of the mechanical structures that are subject to corrosion shall have surface treatments that are consistent with the design life of the telescope (30 years)”

- telescope mast and central tube: RAL 9005 opaque
- all the other structure elements: RAL 3016 opaque

- All painters qualified and certified in accordance with ANSI/NACE N° 13 “Industrial coating and lining application specialist qualification and certification” by Bureau Veritas
- Coordinators and inspectors who validate the cycle and monitor the various activities are NACE certified lev. III