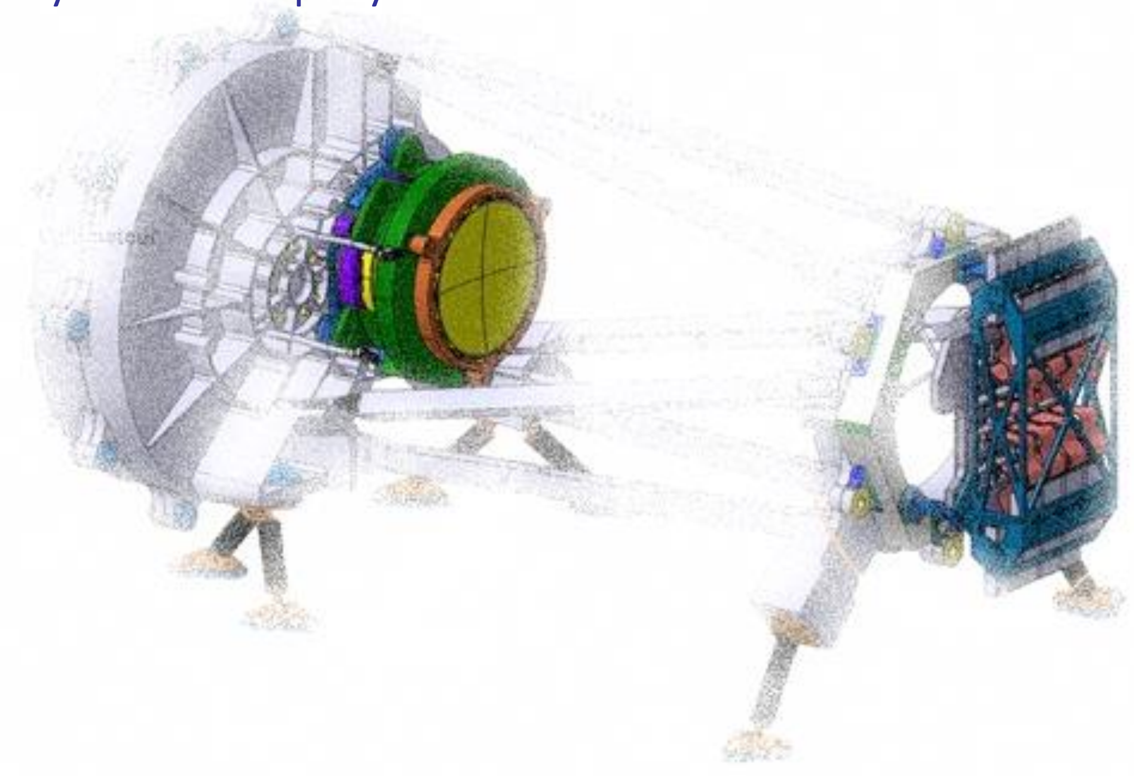
3D metrology inside a vacuum chamber with a laser tracker for NISP test campaign

A. Costille, F. Beaumont, E. Prieto, M. Carle, C. Fabron
Symetrie company for all tests with the mechanical standard



GRD seminar
08/02/2018

Outline of the presentation

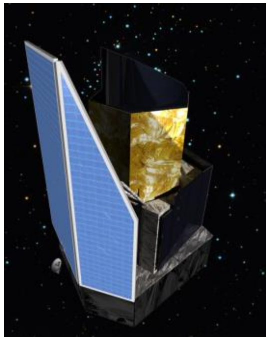
1. EUCLID mission and NISP instrument

2. NISP performance test campaign
   - Goal and description of ERIOS configuration
   - Description of the hardware and GSEs for NISP TB/TV

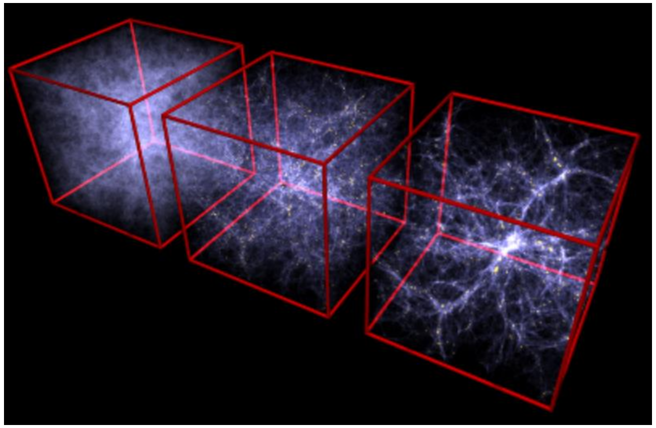
3. Metrology needs for NISP TB/TV

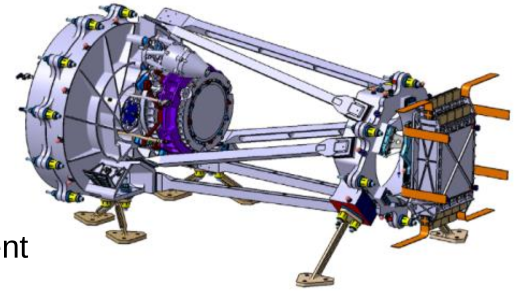
4. Metrology verification plan

5. Test campaign results

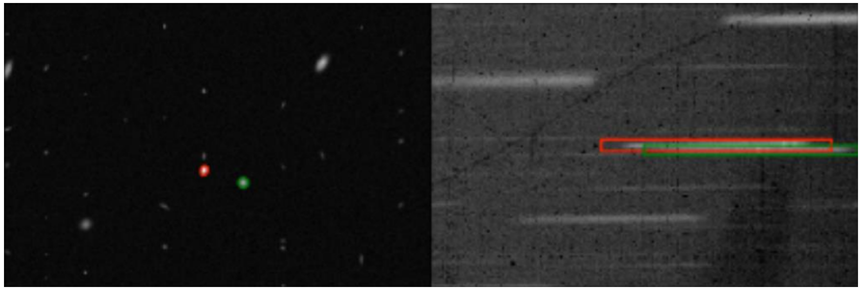


- EUCLID mission: scientific goals
  - ➢ Study of the dark matter distribution and the dark energy in the universe
  - ➢ 3D map of the geometry of the dark universe
- Science done with 2 instruments:
  - ➢ The VIS imager: visible instrument for photometry of the galaxies in the Visible
  - ➢ The NISP: Near Infrared Spectro-Photometer: NIR instrument for
    - ✓ Photometry of the galaxies: position in 2D
    - ✓ Spectroscopy to know precisely the redshift of the galaxies: position in time





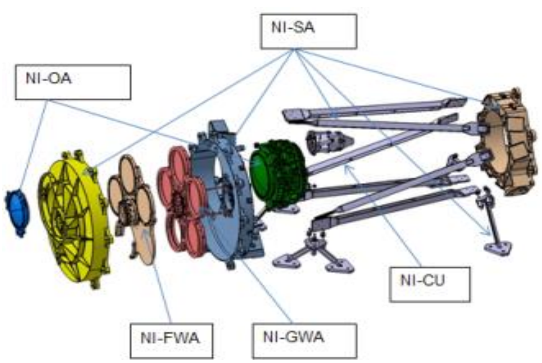
NISP instrument



Credit J. Zoubian

EUCLID mission and NISP instrument

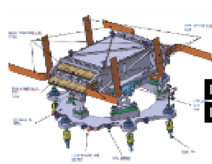
- NISP instrument is made by a consortium of more than 6 countries
  - Project manager of the project is from CNES
  - LAM is responsible of the **development, assembly and test** of the instrument
  - LAM is providing several sub-systems of the instrument: NI-SA, NI-GR, NI-TC
- Instrument will be delivered to ESA in June 2019 (date to be confirmed)



NI-OMA

Mechanics +optical components

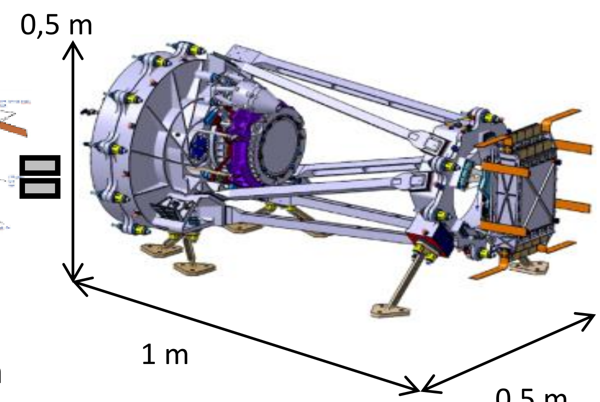
+



NI-DS

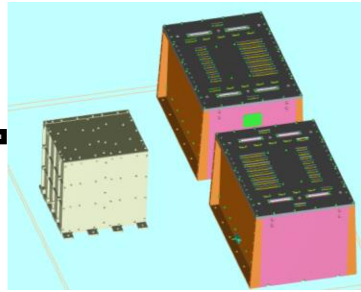
Detection system

=



NIOMADA

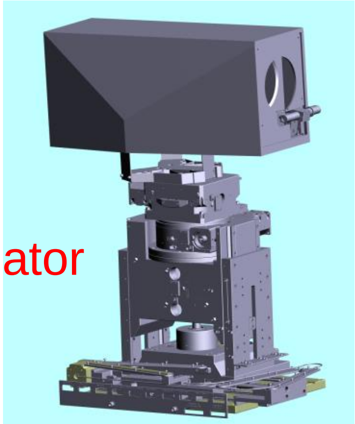
+



Warm Electronics (DPU + ICU)

NISP

- NISP instrument will be fully tested at LAM
  - Functional tests:
    - ✓ Motors movement at cold (filter and grism wheel)
    - ✓ Detector acquisition at cold
    - ✓ NISP thermal behavior at cold



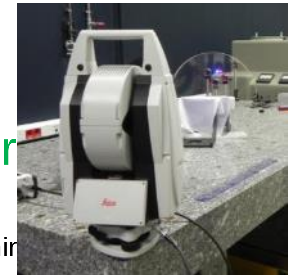
Telescope simulator needed

  - Performance tests:
    - ✓ Detector characterisation at cold with warm electronics
      - Dark, noise, intra-pixel response, linearity, latency, pixel non homogeneity
    - ✓ Optical characterisation at cold
      - FoV verification, plate scale, optical quality (encercled energy)
      - Rough measurement: througput, stray light (verification no big problem)
      - Spectral dispersion full characterisation
  - Optical interfaces with PLM verification at cold
    - ✓ Object plane measurement
    - ✓ Optical axis measurement

ERIOS chamber needed

  - Validation of the calibration strategy at cold
  - Observation strategy test at cold

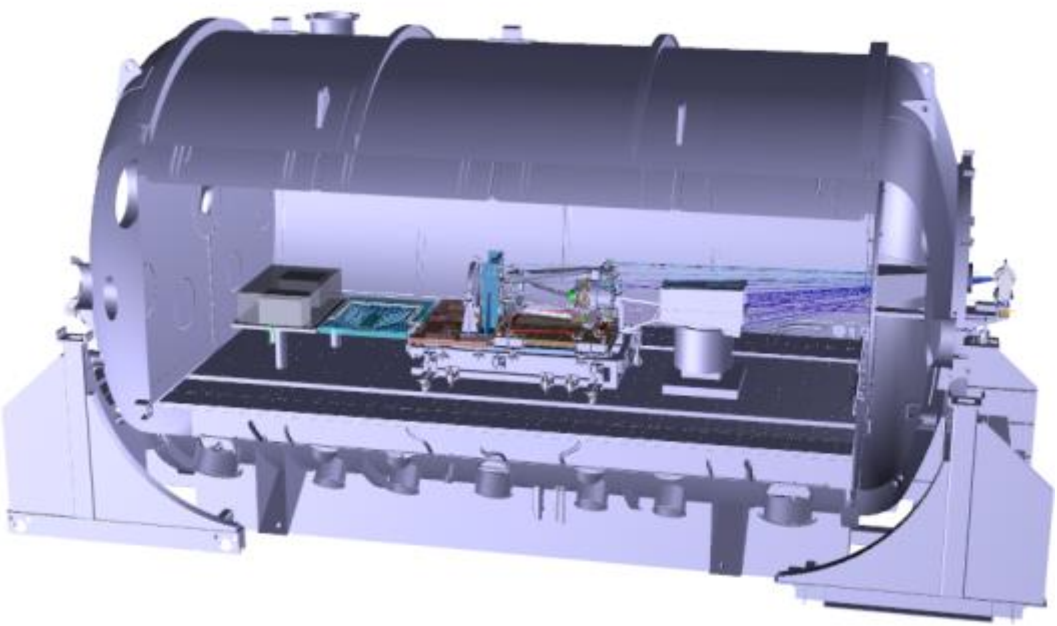
Laser tracker needed



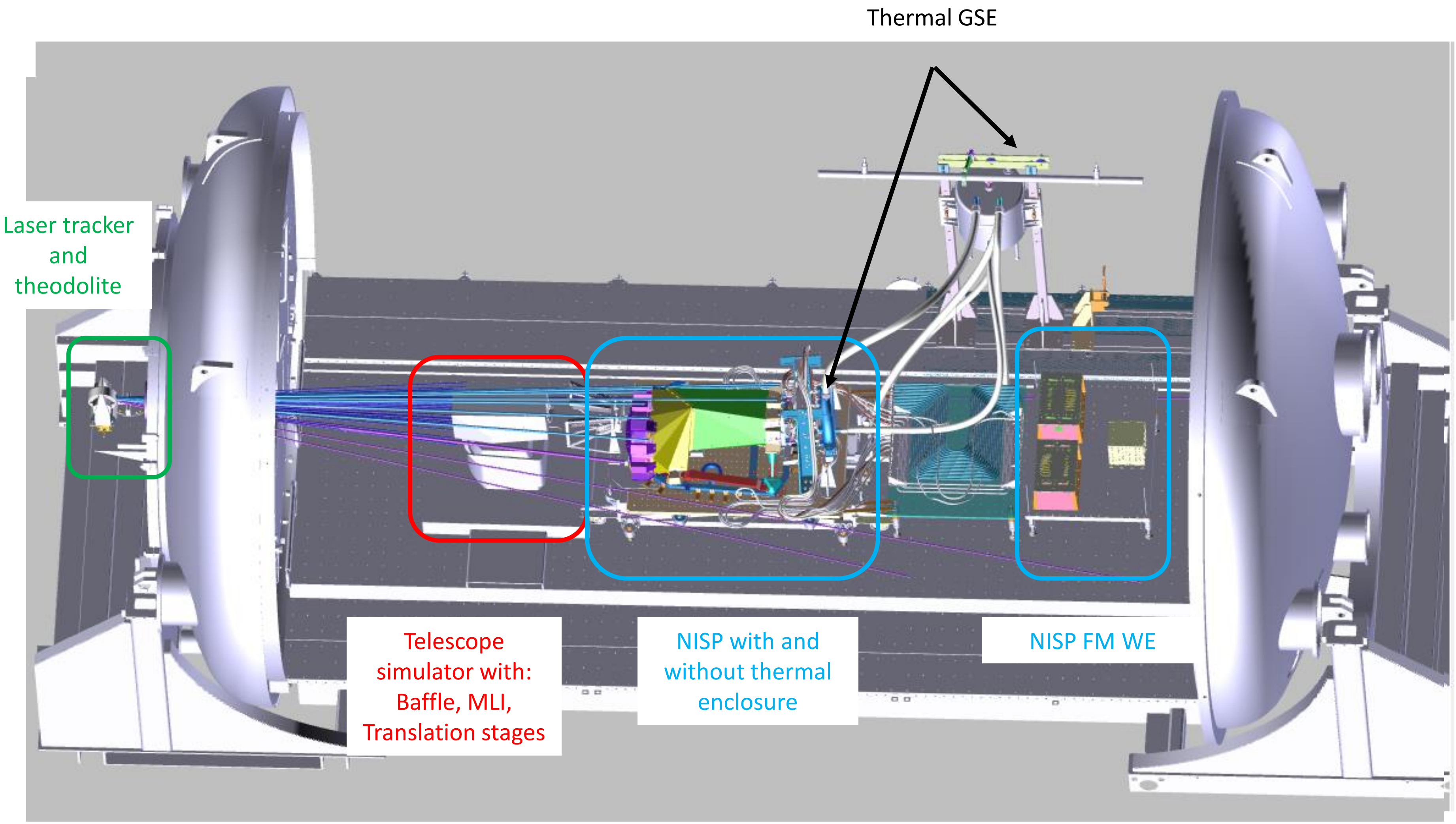
NISP PFM test configuration

- A global mean called the Verification Ground Support (VGS) has been developed for NISP test
- It contains:
  - Optical means (OGSE) with a telescope simulator
  - Thermal and Mechanical means (MGSE & TGSE) to put and maintain the instrument at operational temperature
    - ✓ 130K for the structure, 90K for the detector with a stability lower than 4mK on detectors
  - Metrology mean to measure the positions of the items in real time at cold and vacuum

Inside ERIOS vacuum chamber



NISP PFM test configuration



NISP PFM test configuration

- Design and development of the different GSE is on going:
  - ➢ Validation of the metrology in vacuum: done in September 2017
    - ✓ Will be presented in next slides
  - ➢ Validation of the thermal and mechanical interfaces: done in December 2017
  - ➢ Test and assembly of the OGSE: on going work done by a Danish team
    - ✓ Delivery at LAM in March 2018
    - ✓ Complete test in ERIOS at cold: April 2018

- Today planning for NISP TB/TV test :
  - ➢ Engineering model Test : only mechanics, electronics and software. No optics: July 2018
  - ➢ NISP first TB/TV : NISP instrument with non Flight model detector electronics: October 2018
    - ✓ Fist optical validation, partial characterisation
  - ➢ NISP second TB/ TV: characterisation of the NISP detector with Flight Model detector electronics : January 2018 (TBC)
  - ➢ NISP vibration test: March 2018 (TBC)
  - ➢ NISP final TB/TV : full performance and functional characterisation of NISP instrument before delivery to the payload: May 2018 (TBC)

TMVS hardware

Euclid Consortium

CSS LN2 Tank

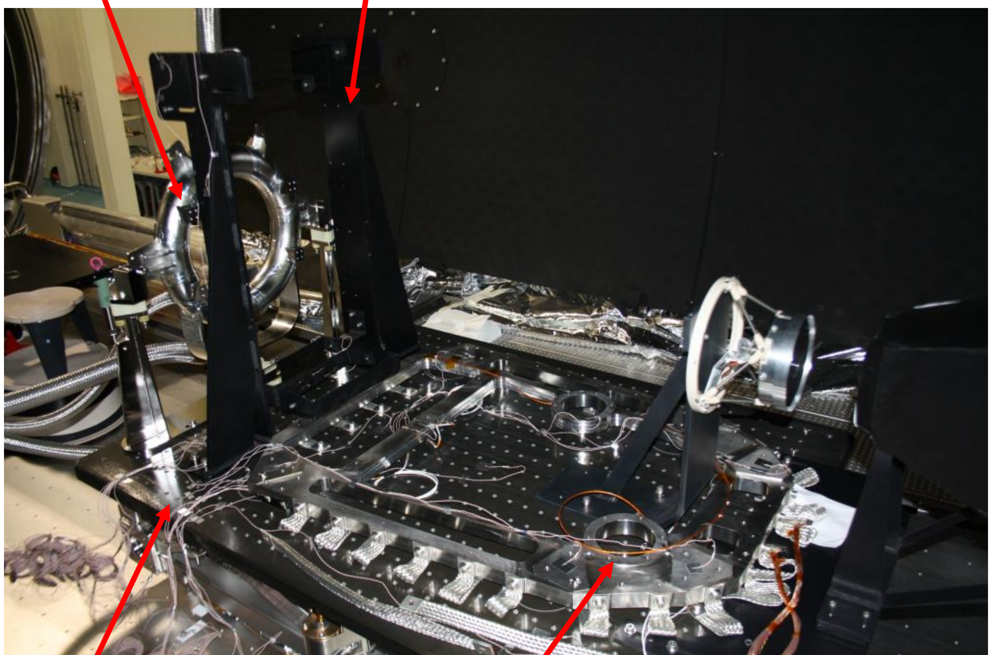
NIDS connector harness ark

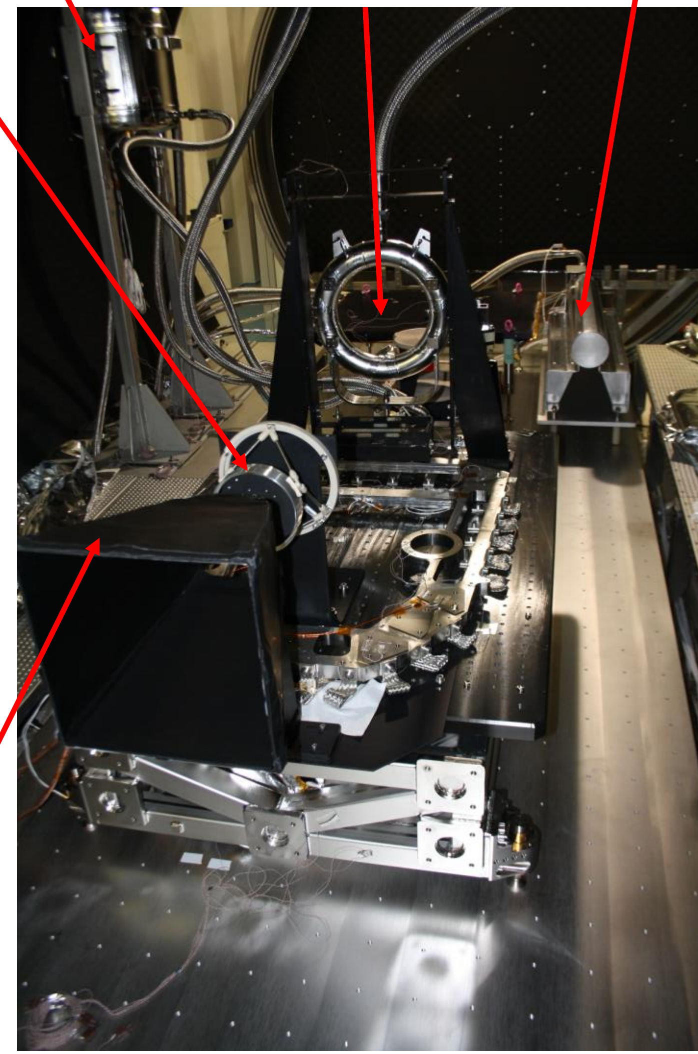
Interface for CPPM detector

NISP Auxiliary tank

WE interface

Cold trap for WE



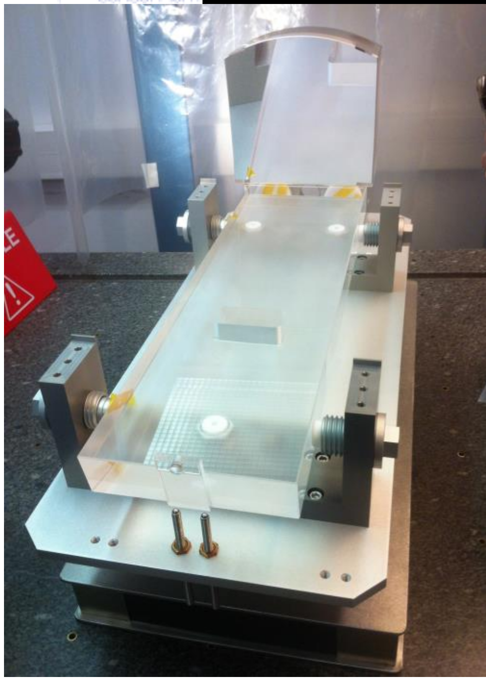


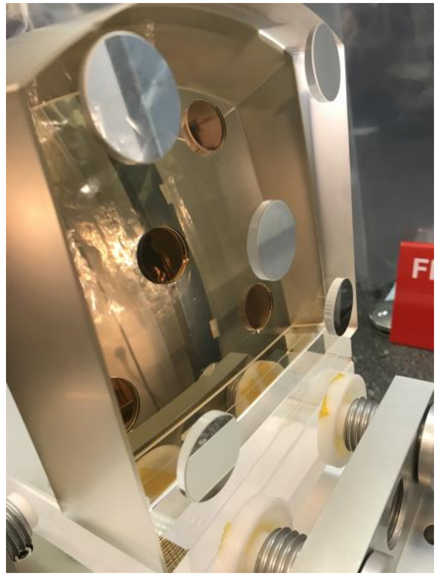
Cold plate

NI-TF: Mechanical interface for NISP feet

NISP-telescope simulator baffle

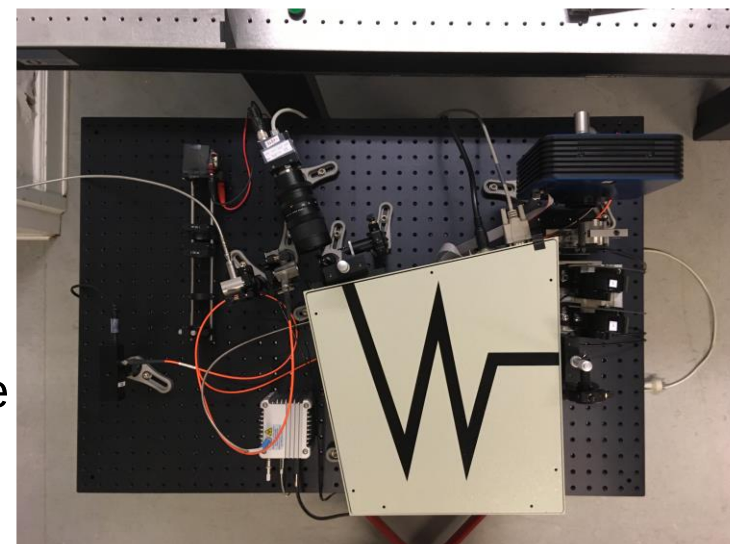
OGSE hardware



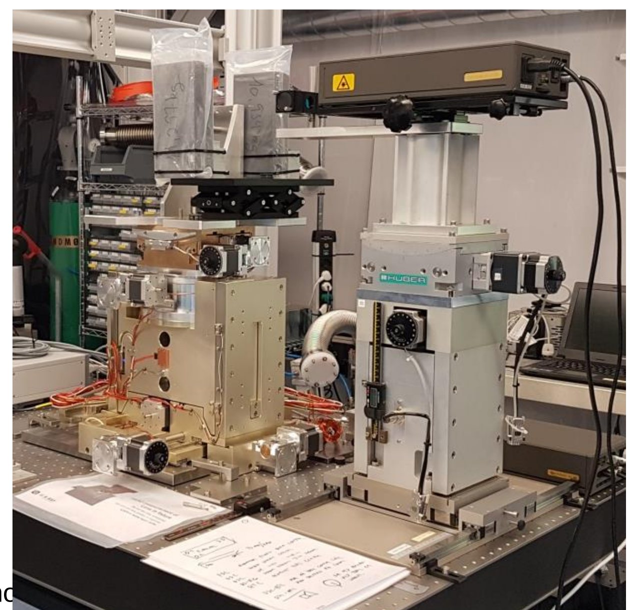


Telescope simulator :
off axis parabola of 160mm diameter
On back-side : small mirrors for theodolite measurement

Light source module (outside erios)

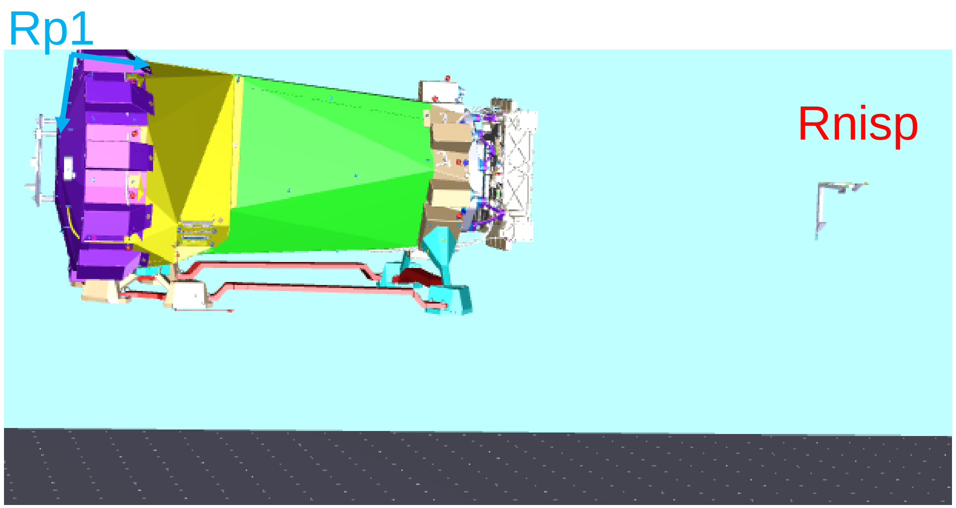


Translation stages under the telescope simulator



Metrology needs for NISP TB/TV

- Goal of the metrology for NISP TB/TV:
  - To measure the best focus plane of NISP instrument with respect to NISP reference frame
  - NISP reference frame = attached to object plane of EUCLID telescope = optical interface between NISP and EUCLID telescope
    - ✓ Need to be simulated during the TB/TV test



The telescope simulator (OGSE) will simulate the focus object of Rnisp $F_{TS}(X,Y,Z)$ during the test for one point of the field

Metrology needs for NISP TB/TV

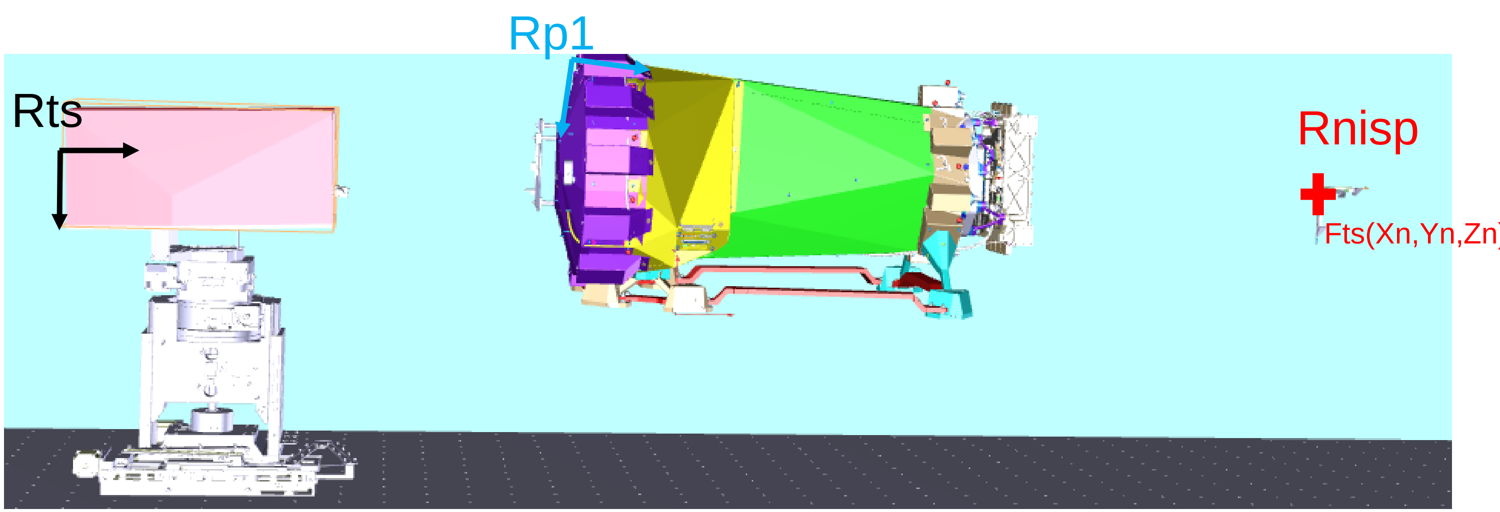
- How do we do ? We measure the relative position of reference frames:
  - R_{TS}: reference frame on the telescope simulator
  - Knowledge of R_{TS} provides the knowledge of the object focal point of EUCLID

$$R_{TS} = M_{TS}\, x F_{TS}$$

  - R_{P1}: NISP reference frame that is linked to NISP detector plane through metrology done at NISP instrument level

- The telescope simulator is focused on 1 point of the NISP FoV
  - We mea
- We repeat t
- We calculate the best focus plane

We need to measure the position of reflectors at cold



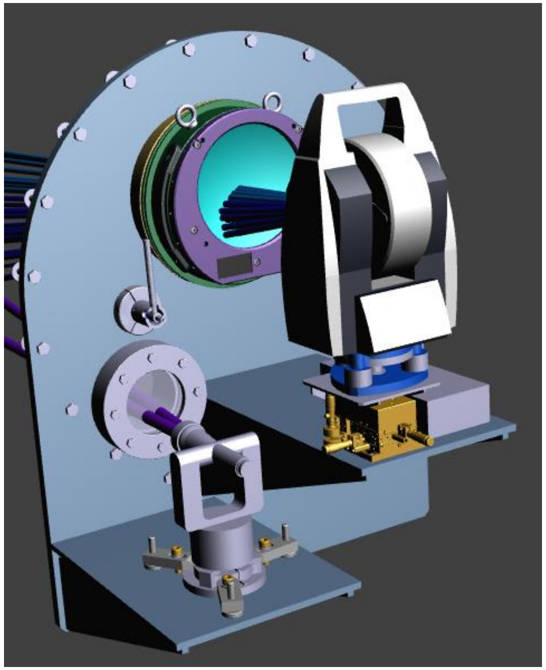
Metrology means for NISP TB/TV

- A laser tracker:
  - Portable coordinates measuring machine provided by LEICA
  - Allow extreme accuracy over large distances
  - It is an accurate theodolite combined with an accur[illegible] measuring equipement

Minimal distance of use	**1.5m**
Maximal distance of use	> 50m
On axis measureme[illegible]	
Resolution	[illegible]
Accuracy	[illegible]
repeatability	[illegible]
3D measu[illegible]	
Angular accuracy	[illegible] /m
Angular resolution	[illegible]
repeatability	[illegible]5µm + 3µm /m

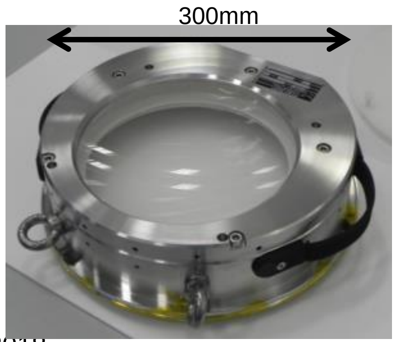
Not compatible with vacuum and cold temperature

Metrology means for NISP TB/TV



- For NISP need:
  - The laser tracker is installed outside ERIOS in front of a window of 180mm clear aperture (35mm thick)
- For the measurement, the laser tracker measures:
  - The return signal from the reflectors (polarimetric signal)
  - Temperature, Pressure, Humidity of the environment to calculate the air index
  - The reflectors will be installed on NISP and TS inside ERIOS (Pvacuum, cold temperature)

- BUT :
  - The laser tracker « does not know » that there is between the reflector and the measurement sets:
    - ✓ A window with index nv
    - ✓ A « vacuum » and cold environment

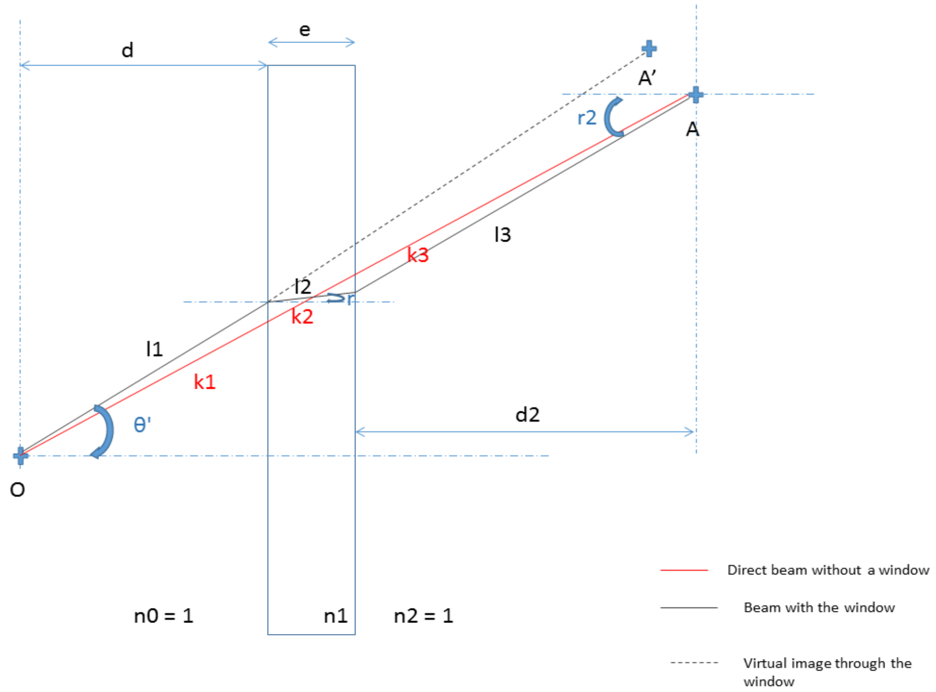


Metrology means for NISP TB/TV

- To validate the use of the laser tracker, we have to answer several questions:
  - Is a measurement possible through a window ? Yes (test done in early 2016)
  - What type of window should be used ? Plane or curved window ?
    - ✓ How the measurement is disturbed by the window ?
    - ✓ What is the impact of the position between the laser tracker and the window ?
    - ✓ What is the error added by the window ?
    - ✓ How do we correct the measurement done ?
  - Is a measurement possible if the laser tracker is installed directly on ERIOS chamber door ? Study during NISP metrology system test campaign
    - ✓ If yes, what is the impact of the vibrations from ERIOS ?
    - ✓ How the position between the window and the laser tracker is disturbed by ERIOS environment
    - ✓ What is the impact on the window of ERIOS environment (vacuum, cold) ?
  - How the reflectors behave at cold ? They survive (test done in early 2016)
    - ✓ If yes, what is the impact on the measurement error ?
  - What is the measurement error ?

Choice of the window type

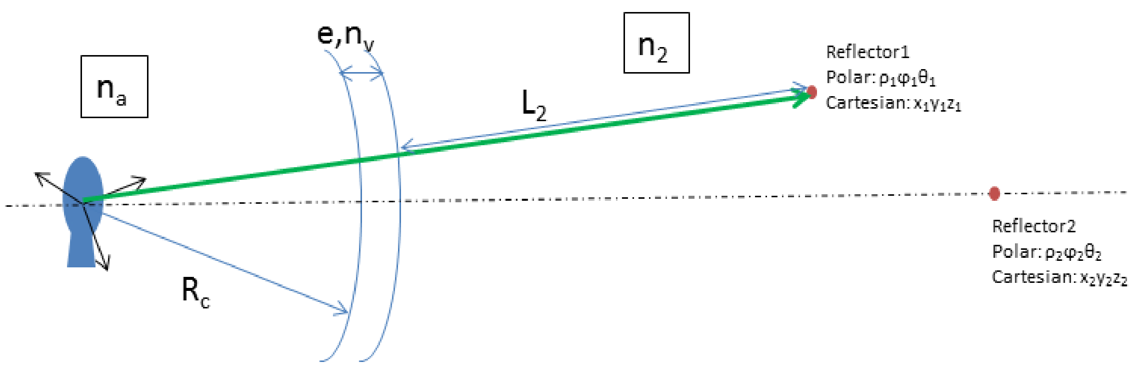
- 2 solutions are possible:
  - Use a classic parallel plate as a window
    - ✓ The window will move the object position from the laser tracker
    - ✓ 3D equations of the light propagation should be written to correct the measurement done by the laser tracker



Choice of the window type

- 2 solutions are possible:
  - Use a classic parallel plate as a window
    - ✓ The window will move the object position from the laser tracker
    - ✓ 3D equations of the light propagation should be written to correct the measurement done by the laser tracker
  - Use a « curved » window = concentric concave surfaces
    - ✓ If the laser tracker is placed at the center of curvature of both faces, the beam is not deviated by the window
    - ✓ The error on the measurement will only be on the distance measurement, not on the angular position
    - ✓ Using light propagation time, we calculate the following correction law:

$$L = Rc + e + L_2 = \frac{n_a}{n_2} L_m + Rc(1 - \frac{n_a}{n_2}) + e(1 - \frac{n_v}{n_2})$$



Verification plan for metrology

- Goal of the verification plan is to demonstrate the feasability and the performance of the metrology for NISP test
  - What accuracy can be reached for measurement at cold and vacuum with a laser tracker ?
- Preliminary tests have shown that the main impact of the laser tracker errors was:
  - The window
  - The vacuum
  - Impact of cold temperature was negligible
- It has been decided to focus the verification strategy on effect of vacuum
  - Adding test at cold was too restrictive

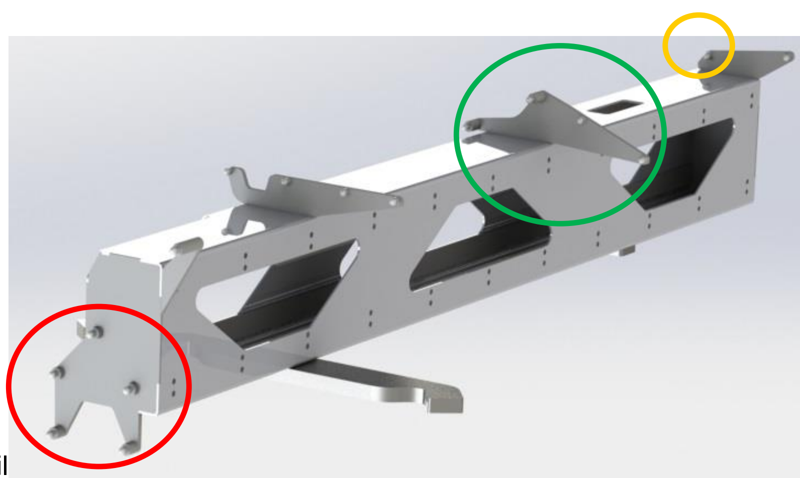
Verification plan for metrology

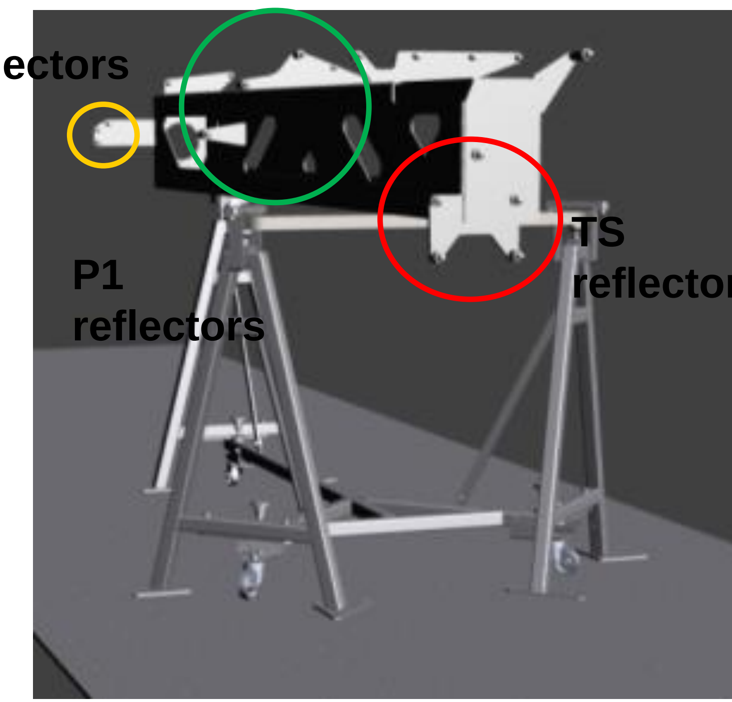
- Verification plan strategy
  - To have a standard mechanical part representative of the NISP TB/TV test configuration to know what we are measuring
  - To perform a sequential analysis
    - ✓ Knowledge of the frame
    - ✓ Measurement of the frame with a laser tracker no window
      - Estimation of the laser tracker uncertainties
    - ✓ Measurement of the frame with a laser tracker through the curved window
      - Estimation of the error introduced by the window
    - ✓ Measurement of the frame with a laser tracker through the curved window in vacuum in ERIOS
      - Estimation of the error introduced by the vacuum and ERIOS conditions
    - ✓ Measurement during VGS blank test at cold
      - Validation that the cold is not added errors on the measurement

- Work has been done in collaboration with Symetrie company

Verification plan for metrology

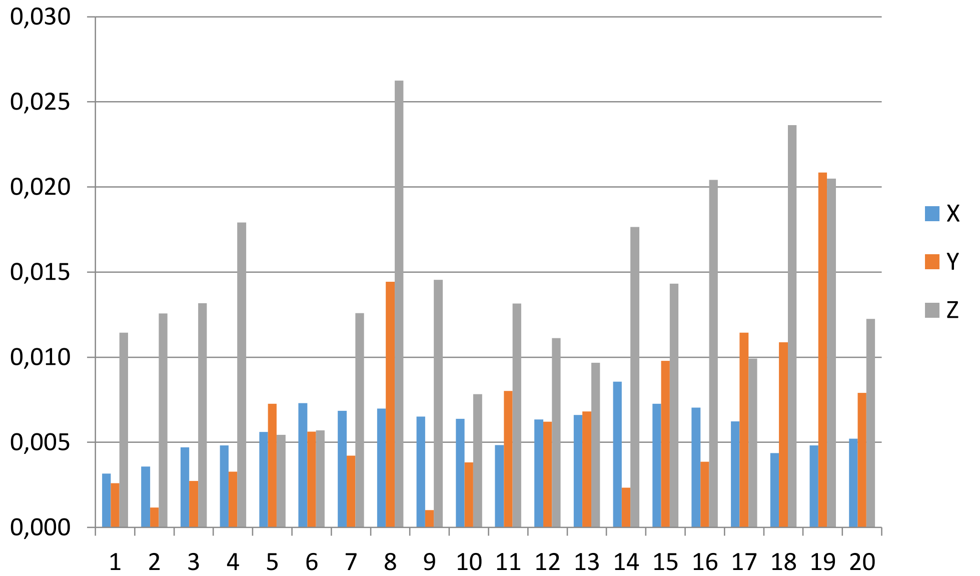
- Symetrie company was in charge of:
  - ➢ The design of the mechanical standard
  - ➢ The measurement and analysis of the mechanical standard with:
    - ✓ The CMM
    - ✓ The laser tracker
    - ✓ The curved window: work done in colloboration with LAM for alignment and measurement with the window
- The mechanical standard reproduces:
  - ➢ TS reflectors positions
  - ➢ P1 and P3 reflectors positions
  - ➢ other planes has been added for analysis
- Design of the mechanical standard ensures its stability with temperature and time





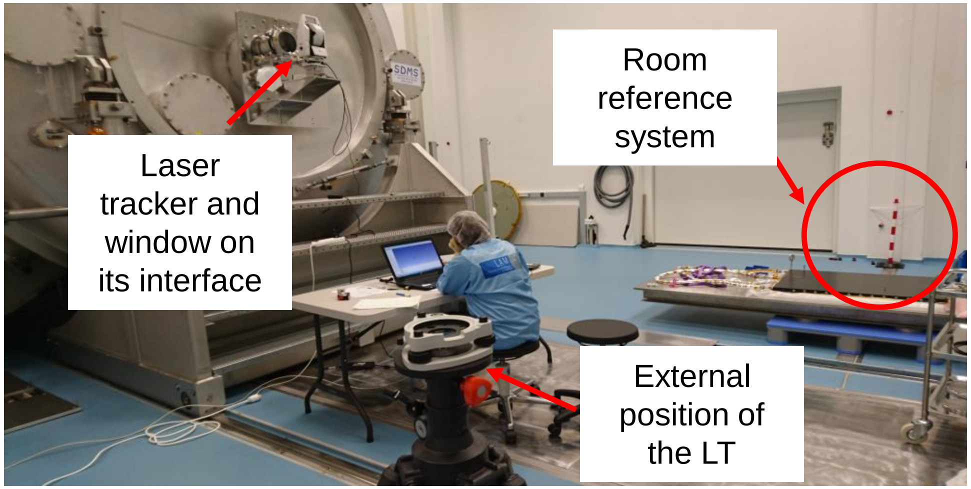
Metrology validation campaign

- Measurement of the mechanical standard with a CMM
  - Definition of a reference system on the mechanical standard Ret to locate precisely position of each reflector on the frame: (X0, Y0, Z0)
  - Measurement uncertainties: 13,2µm +1,8^{e}-6L
- Measurement with the laser tracker without a window
  - To estimate error budget from the laser tracker alone
  - Uncertainties of the reflectors positions is different from the axis measured
    - ✓ Better uncertainty reached for measurement in X direction (optical axis): better than 10µm
    - ✓ Lower uncertainty reached for measurement in Y and Z direction: around 20µm
  - Measurement uncertainties: 62µm + 2,7^{e}6L



Metrology validation campaign

- Alignment between the laser tracker and the curved window on the window curvature center
  - Metrology of the window is done
    - ✓ A cartesian coordinate system is defined to locate the center of curvature Rw
  - The LT locates Rw in a room reference system
  - Laser tracker is installed on its interface and move to align the laser tracker center on Rw in the room reference system
  - Alignment better than 300µm is reached



Metrology validation campaign

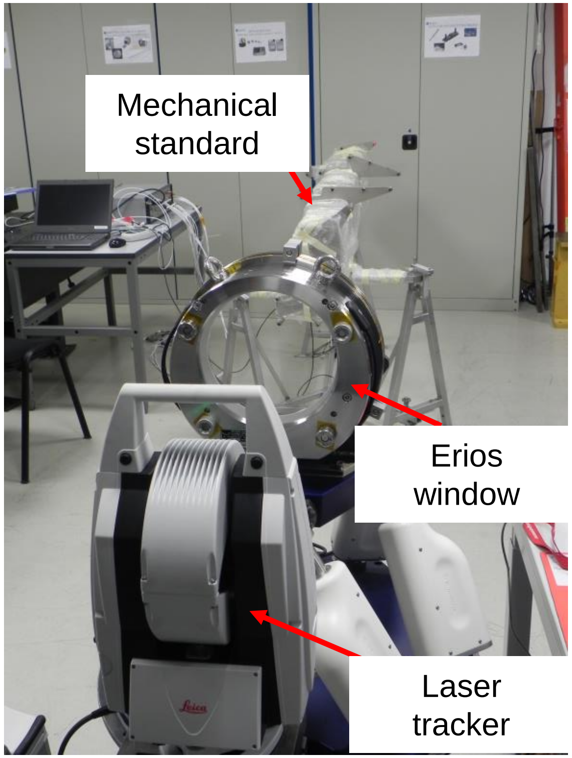
- Measurement of the mechanical standard with the laser tracker through the window
  - Coordinates (X2, Y2, Z2) for each reflectors in Ret
  - In spherical coordinates, a constant error in distance is measured: 13,93mm
    - ✓ Consistent with the impact of the glass: d = e(nv-na)
  - Coordinates (X3, Y3, Z3) are calculated with constant error correction
  - Difference between (X3, Y3, Z3) and (X0, Y0, Z0) is calculated
  - Difference better than 30µm (mean values on each reflectors coordinates)

(ρ2,θ2,φ2) - (ρ0,θ0,φ0)

Bille #	Δρ (mm)	Δθ (°)	Δϕ (°)
BILLE_1	13,929	-0,005	-0,009
BILLE_2	13,925	-0,005	-0,010
BILLE_3	13,924	-0,005	-0,009
BILLE_4	13,927	-0,005	-0,009
BILLE_5	13,926	-0,005	-0,009
BILLE_6	13,925	-0,005	-0,009
BILLE_7	13,930	-0,005	-0,009
BILLE_8	13,930	-0,005	-0,009
BILLE_9	13,928	-0,005	-0,009
BILLE_10	13,928	-0,005	-0,009
BILLE_11	13,927	-0,005	-0,009
BILLE_12	13,930	-0,005	-0,009
BILLE_13	13,929	-0,005	-0,009
BILLE_14	13,931	-0,005	-0,009
BILLE_15	13,934	-0,005	-0,009
BILLE_16	13,940	-0,005	-0,009
BILLE_17	13,940	-0,004	-0,009
BILLE_18	13,933	-0,005	-0,009
BILLE_19	13,931	-0,004	-0,009
BILLE_20	13,936	-0,004	-0,009
Min	13,924	-0,005	-0,010
Max	13,940	-0,004	-0,009
Moy	13,930	-0,005	-0,009
Ecart Type	0,005	0,000	0,000

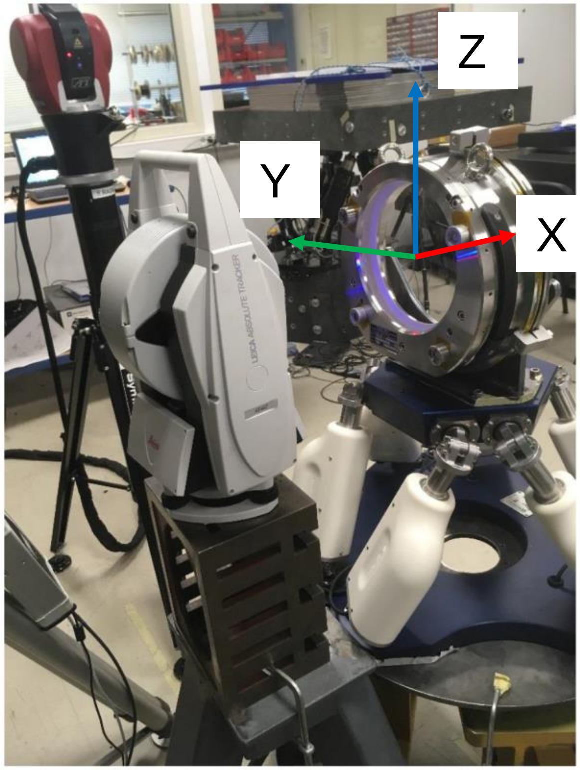
(ρ3,θ3,φ3) - (ρ0,θ0,φ0)

	Correction ρ			Correction ρ θ ϕ		
Bille #	ΔX (mm)	ΔY (mm)	ΔZ (mm)	ΔX (mm)	ΔY (mm)	ΔZ (mm)
BILLE_1	0,015	0,034	-0,005	0,015	0,029	-0,005
BILLE_2	0,016	-0,003	0,031	0,016	-0,007	0,030
BILLE_3	0,011	0,023	0,015	0,011	0,021	0,016
BILLE_4	0,012	0,014	0,017	0,012	0,013	0,017
BILLE_5	0,010	0,025	-0,006	0,010	0,025	-0,005
BILLE_6	0,005	0,013	-0,012	0,005	0,013	-0,012
BILLE_7	0,004	0,019	-0,013	0,004	0,019	-0,014
BILLE_8	0,000	0,000	0,000	0,000	0,000	0,000
BILLE_9	0,004	-0,005	0,000	0,004	-0,005	0,001
BILLE_10	0,000	-0,011	0,000	0,000	-0,011	0,000
BILLE_11	0,003	-0,021	0,023	0,003	-0,023	0,022
BILLE_12	0,001	0,000	0,014	0,001	-0,001	0,014
BILLE_13	-0,004	-0,008	0,006	-0,004	-0,008	0,006
BILLE_14	-0,003	-0,008	-0,013	-0,003	-0,008	-0,013
BILLE_15	0,000	-0,005	-0,007	0,000	-0,004	-0,008
BILLE_16	0,000	0,000	0,000	0,000	0,000	0,000
BILLE_17	-0,001	0,035	0,013	-0,001	0,034	0,014
BILLE_18	-0,002	0,028	0,023	-0,002	0,026	0,023
BILLE_19	-0,008	-0,011	0,040	-0,008	-0,013	0,040
BILLE_20	0,003	0,023	0,025	0,003	0,021	0,025
Min	-0,008	-0,021	-0,013	-0,008	-0,023	-0,014
Max	0,016	0,035	0,040	0,016	0,034	0,040
Moy	0,003	0,007	0,008	0,003	0,006	0,008
Ecart Type	0,006	0,017	0,016	0,006	0,017	0,016



Metrology validation campaign

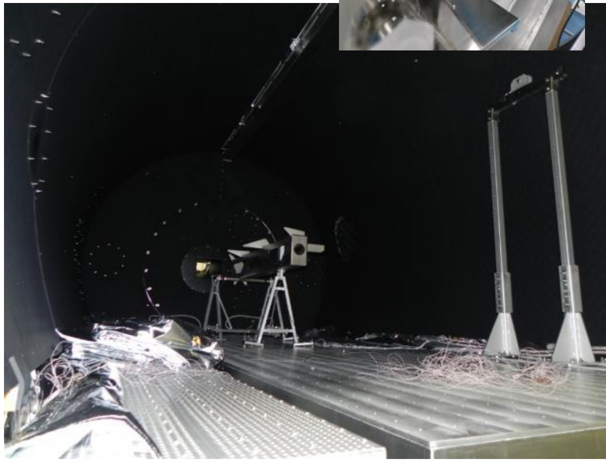
- Sensibility analysis done between the position of the window and the laser tracker
  - Window is moved in each direction of +/-3mm
  - Impact of the difference is calculated
  - Error added by the window is lower than 30µm when the laser tracker is aligned around +/-1mm from the curvature center
  - More impact if we move along the optical axis of the window



Metrology validation campaign

- Test of the MVS at Pvacuum and Tambient is Erios has been done in September 2017:
  - ➢ The mechanical standard has been installed inside ERIOS
  - ➢ Reflectors coordinates are compared to the value of the measurement standard coordinates on the CMM

- This test has allowed:
  - ➢ Validating the alignment procedure of the laser tracker with the curved window
  - ➢ Validating of the correction factor to be applied to the data at Pambient and Pvacuum
  - ➢ Estimating the measurement uncertainties at Pvacuum



Metrology validation campaign

- With the window alone, impact on the laser tracker measurement
  - Error of 13,93mm in the distance measurement (in spherical coordinates)
  - Impact on angle measurement values negligible (θ,ϕ)

- Hypothesis taken for the impact of the vacuum on the laser tracker measurement
  - Error on the distance measurement linked to:
    - ✓ The window
    - ✓ The vacuum index (=1)
  - Impact on angle measurement values negligible(θ,ϕ)
  - The laser tracker is aligned on the window curvature center better than +/-1mm

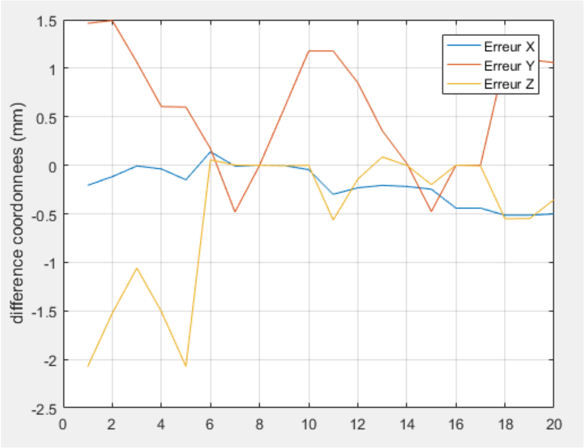
- We propose to apply the correction factor:

$$\rho_{corr} = \rho_{mes} - 13.93\text{mm} + (n_a - 1) * (\rho_{mes} - 13.93 - 300)$$

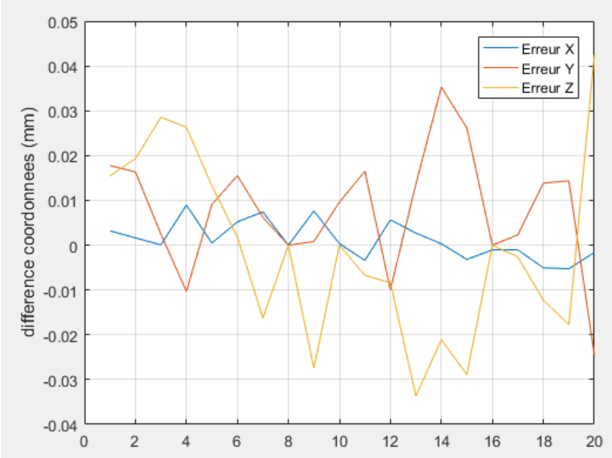
- Analysis done with the comparison of the reflectors coordinates measured with the laser tracker and a CMM
  - Coordinates difference in (X,Y,Z)

$$diff = \sqrt{(x_{lt} - x_{CMM})^2 + (y_{lt} - y_{CMM})^2 + (z_{lt} - z_{CMM})^2}$$

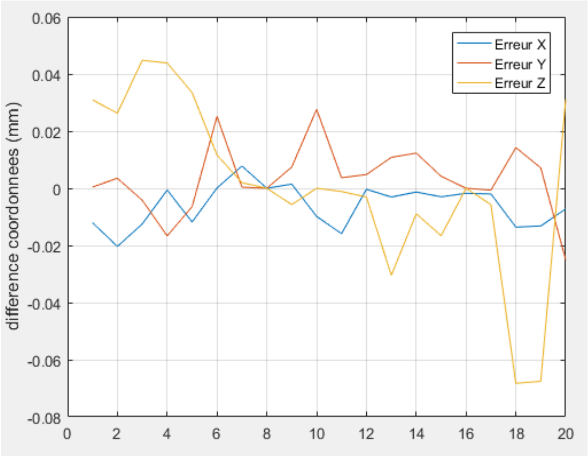
  - Residual Error on the coordinates lower than 60µm ie lower than measurement uncertainties



No correction of the data



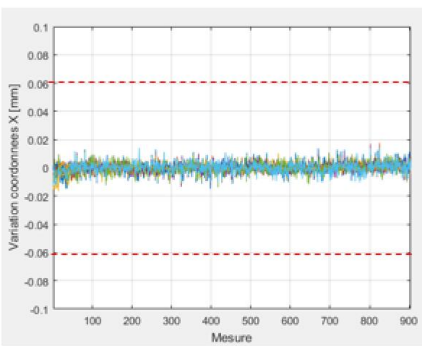
Correction of the data at Pambient

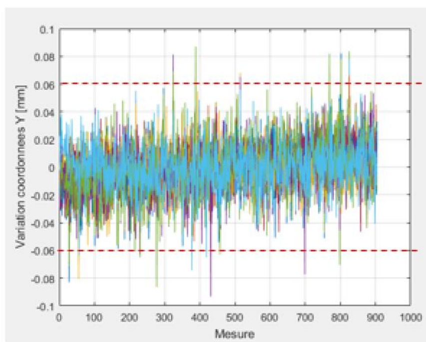


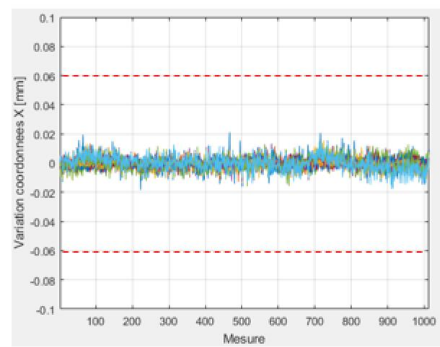
Correction of the data at Pvacuum

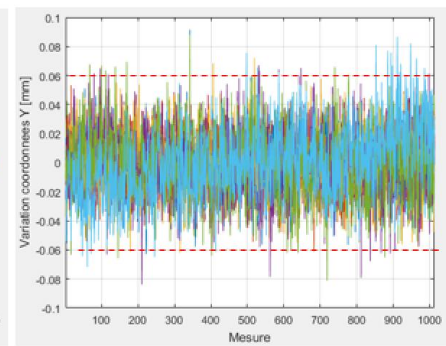
Metrology validation campaign

- Measurement repeatability similar at Pambient and Pvacuum
  - ➢ Uncertainties on X axis: < +/-15µm
    - ✓ Same values as measurement with a laser tracker without a window
  - ➢ Uncertainties on Y and Z axis : < +/-60µm
    - ✓ Same values as measurement with a laser tracker without a window
  - ➢ Small increase of the uncertainties at Pvacuum due to the environment: not critical
- For measurement in Erios, an average of 5 measurements will be considered

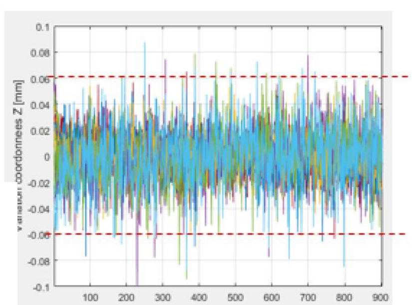




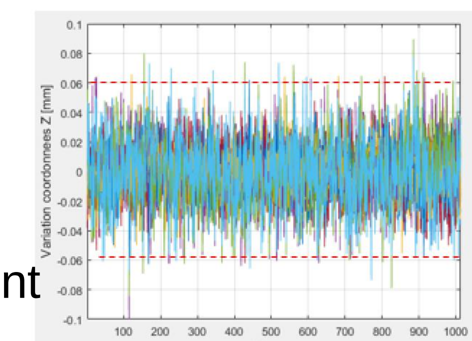




Pambient measurement

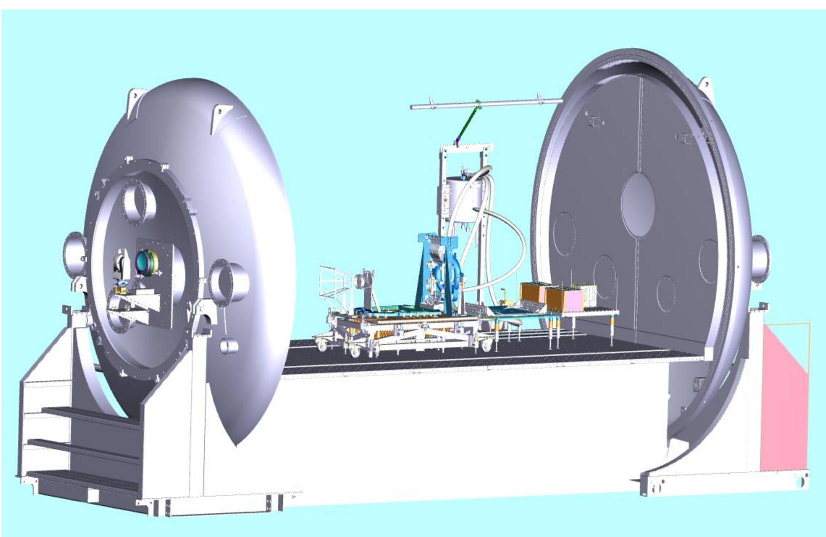


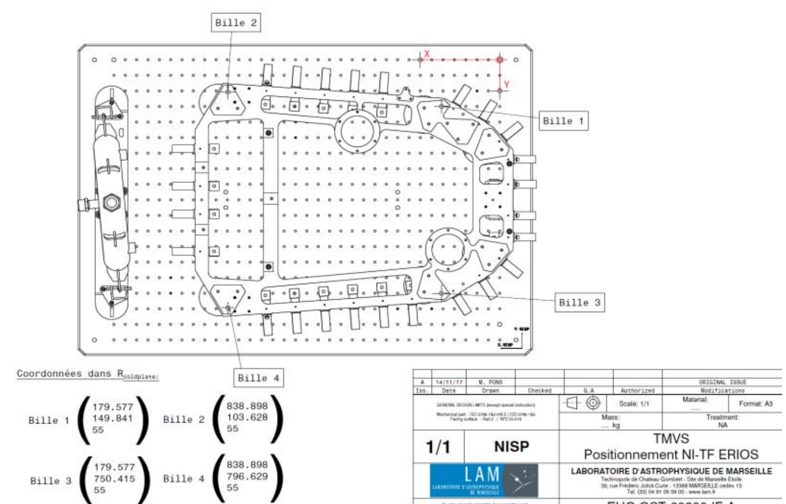
Pvacuum measurement



Metrology validation campaign

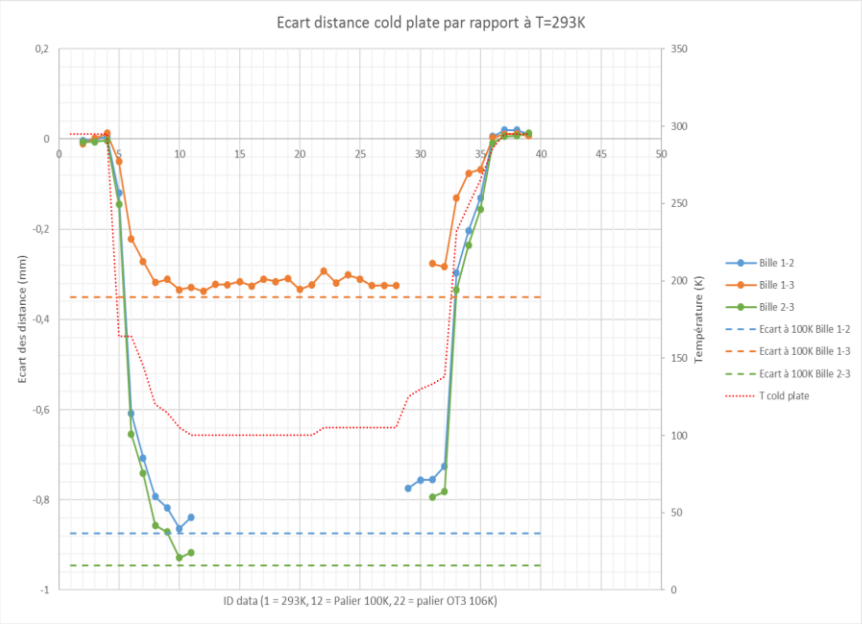
- Additional test has been performed at cold in December 2018
- During the blank test of the thermal and mechanical GSE of NISP, we have put:
  - 3 reflectors on an aluminium plate
  - 4 reflectors on an invar plate (NISP feet interface)
- Goal of the test was:
  - To validate the measurement of reflectors at cold
    - ✓ No deteriotation of the reflector due to cold
    - ✓ No measurement issue
    - ✓ No impact of the cryopump on laser tracker measurement
  - To estimate if an additional correction factor is needed at cold

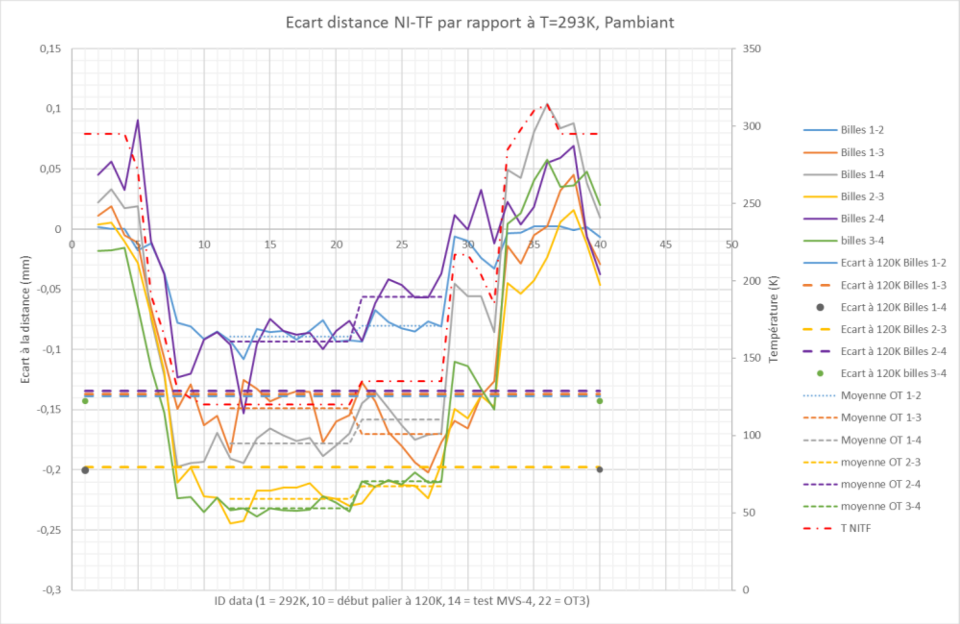




Metrology validation campaign

- Test was considered as successful as:
  - All reflectors are still « intact » after cold temperature and keep their measurement accuracy
  - Measurement repeatability at cold was similar to the one measured at Pvacuum and Tambient:
    - ✓ Increase of the measurement repeatability with this configuration as the interfaces are less stable mechanicaly
  - No additional « cold » correction has been identified
    - ✓ Inter-reflector target distance has been measured and compared to estimated cold distance with CTE knowledge
    - ✓ Data still under analysis





CONCLUSION

- Test campaign done at LAM has demonstrated the feasility of the laser tracker measurement for NISP TB/TV
  - Is a measurement possible through a window ? Yes
  - What type of window should be used ? Curved window
    - How the measurement is disturbed by the window ? Distance to be corrected by a constant value from the window + variable due to index variation
    - What is the impact of the position between the laser tracker and the window ? Robustness of the aligment has been observed
    - What is the error added by the window ? « nothing » after correction law application
    - How do we correct the measurement done ? Correction law identified
  - Is a measurement possible if the laser tracker is installed directly on ERIOS chamber door ? YES
    - If yes, what is the impact of the vibrations from ERIOS ? Increase of measurement repetability => on X axis < 20µm; on Y and Z axis < 60µm
    - How the position between the window and the laser tracker is disturbed by ERIOS environment : no major impact observed
    - What is the impact on the window of ERIOS environment (vacuum, cold) ? No impact
  - How the reflectors behave at cold ? They survive (test done in early 2016)
    - If yes, what is the impact on the measurement error ? Impact lower than the other error term
  - What is the measurement error ? Measurement error from the laser tracker at cold and vacuum : +/-80µm (tbc)

Conclusion

- We have a metrology mean for the NISP TB/TV test campaign
- We have understood the measurement from the laser tracker through a window
- We have developed a method to correct the measurement
- Uncertainties budget still need to be consolidated
  - Will be done thanks to next test campaign
- At the end of NISP test campaign, we will be able to offer this metrology mean for all test campaign done in ERIOS