**Title** **AHEAD JRA, WP 6.6 - Optical Blocking Filters for Cryogenic Detectors: 30th month report "H/W Components and Status"**


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|---|---|---|---|
| Prepared by : | M. Barbera, L. Sciortino | Date | : 13/04/2018 |
| Inputs by: | Fabio D'Anca, Ugo Lo Cicero, Salvatore Ferruggia Bonura | Date | : 17/04/2018 |
| Checked by : | Lorenzo Natalucci | Date | : 24/04/2018 |
| Agreed by: | Jan-Whillem den Herder | Date | : 24/04/2018 |


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| Issue | Date | Changed Section | Description of Change |
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| 1.0 | 13.04.2018 | | First Issue |
| 1.1 | 27.04.2018 | Section 2. additional information on trade-off analysis<br><br>Section 4. additional information on vibration and acoustic test levels<br><br>Section 5. new section with references to published papers and technical reports. | |
| | | | |

## ABBREVIATIONS AND ACRONYMS

| ITEM | MEANING |
|---|---|
| ATHENA | Advanced Telescope for High ENergy Astrophysics |
| AC | Aperture Cylinder |
| CA | Control Accelerometers |
| CSL | Centre Spatial de Liège |
| CTE | Thermal Linear Expansion Coefficient |
| CG | Centre of Gravity |
| CNR | Consiglio Nazionale delle Ricerche |
| DIFC | Dipartimento di Fisica e Chimica |
| DM | Demonstration Model |
| EM | Engineering Model |
| EMI | Electro Magnetic Interference |
| ESA | European Space Agency |
| FE | Finite Element |
| FEA | Finite Element Analysis |
| FEM | Finite Element Model |
| FOV | Field Of View |
| FPA | Focal Plane Assembly |
| GBF | Geometrical Blocking Factor |
| AHEAD | integrated Activities for the High Energy Astrophysics Domain (H2020-INFRAIA-2014-2015, project N. 654215) |
| INAF | Istituto Nazionale di AstroFisica |
| LM | Lithographic Mesh |
| NA | Not Applicable |
| OAPA | Osservatorio Astronomico di Palermo |
| OBF | Optical Blocking Filter |
| PSD | Power Spectral Density |
| RF | Radio Frequency |
| RT | Room Temperature |
| SCF | Stress Concentration Factors |
| SI-XIFU | Shaker Interface for X-IFU filters |
| SM | Structural Mesh |
| SQUID | Superconducting Quantum Interference Device |
| SS | Stainless Steel |
| TBC | To Be Confirmed |
| TBD | To Be Defined |
| TF | Thermal Filter |
| TN | Technical Note |
| UNIPA | Università degli Studi di Palermo |
| WFI | Wide Field Imager |
| X-IFU | X-ray Integral Field Unit |
| | |
| $1\sigma$ | Root Mean Square value of random vibration analysis results |
| $3\sigma$ | Three times the Root Mean Square value of random vibration analysis results |

# REFERENCE DOCUMENTS

20170410_Report_BCV_p2784_rep4_i1.pdf (Vibration Test Report, CSL March 27-30, 2017)
X_IFU_FILTER_ATHENA-01-03_D56.pdf (mech. drawings of X-IFU Thermal Filter D=56 mm)
X_IFU_FILTER_ATHENA-01-03_D100.pdf (mech. drawings of X-IFU Thermal Filter D=100 mm)
TF130S_Luxel.pdf (mech. Drawings of LUXEL TF130S filter frame)

# INDEX

# 1. FOREWORD

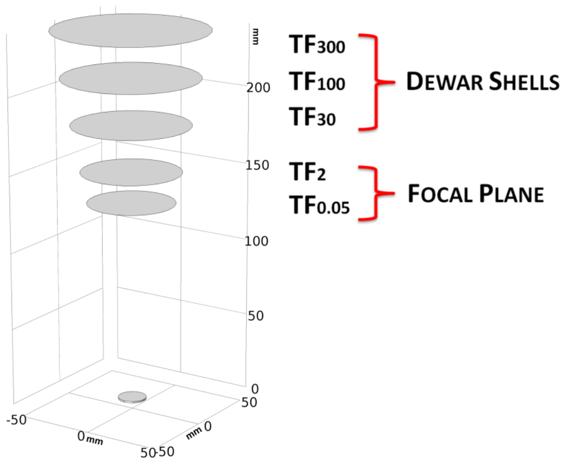
We report hereafter a description of the procured filter samples and a brief report of the experimental campaigns carried out on them as a part of the activities of AHEAD JRA – WP6.6 "Optical Blocking Filters for Cryogenic Detectors" after 30 months from the program beginning.

Cryogenic detectors require thermal/optical blocking filters to thermally insulate the sensors, operating at sub-K level, from the satellite environment (typically at room temperature). Such detectors, in order to fully exploit their capabilities, need also to be protected by contamination and Radio Frequency EMI mainly coming from the telemetry antenna and spacecraft operation. Since no filters exist which are thermally insulating, RF insulating and transparent to X-ray energies, a significant challenge is to find a design solution which minimize the loss in effective area still ensuring all requirements including the mechanical robustness to survive launch.

As part of the AHEAD JRA WP 6.6 "Optical Blocking Filters for Cryogenic Detectors" activities, after 30 months from the program beginning,  we report hereafter a description of the procured filter samples and of the experimental campaigns carried out on them. A significant and driving case study in this WP has been the development of the X-Ray Integral Field Unit (X-IFU) detector on board the ATHENA large mission of the European Space Agency.

# 2. ATHENA X-IFU THERMAL FILTERS INVESTIGATED DESIGN

In the current design of the ATHENA X-ray Integral Field Unit, reported in figure 1, five filters are expected to work at five different temperatures corresponding to the cryostat shields temperatures. The filters are assembled in two groups with respect to the location in the instrument: the outers marked as the dewar shell group and the inners as the focal plane assembly group.



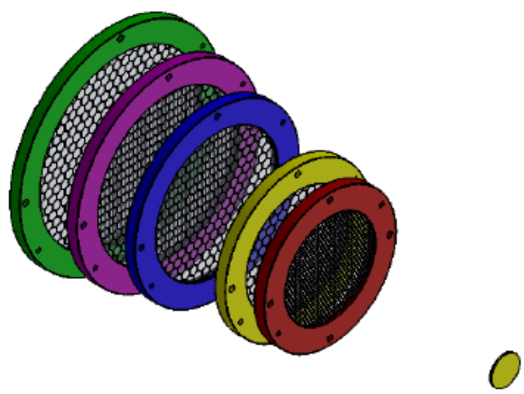



**Figure 1**. Left panel: Current geometric configuration of the filters with respect to the focal plane detector. Two different groups are identified with respect to the location in the instrument: the outer filters are marked as the dewar shell group, while the inner ones as the focal plane assembly group. Right panel: Current design of the structural supporting meshes of the filters.

Each filter consists of a thin polyimide membrane (45 nm thick) coated with aluminum film (~30 nm thick) and is named using the acronym TF for thermal filter followed by the value of the nominal temperature, that are 300 K, 100 K, 30 K for the dewar shell group and 2 K and 0.05 K for the focal plane group, respectively. To give mechanical robustness to the membrane a honeycomb supporting mesh (SS 304, Nb) (~ 3% Blocking Factor) is currently foreseen with 5 µm thick Au plating on SS mesh to absorb Fe fluorescence lines. The meshes also provide thermal conductance and partial RF attenuation. The filter parameters are summarized in table 1.

**Table 1** Parameters for the filters.

| Filter | T (K) | Z (mm) | D (mm) | Mesh pitch (mm) | Mesh material | Wire thickness (µm) | Wire Width (µm) | Blocking Fatctor (%) |
|---|---|---|---|---|---|---|---|---|
| TF300 | 300 | 240 | 100 | 5 | Au/AISI 304 | 130 | 65 | 3 |
| TF100 | 100 | 210 | 87 | 5 | Au/AISI 304 | 130 | 65 | 3 |
| TF30 | 30 | 180 | 75 | 5 | Au/AISI 304 | 130 | 65 | 3 |
| TF2 | 1 | 130 | 64 | 2 | Au/AISI 304 | 60 | 30 | 4 |
| TF0 | 0.05 | 110 | 56 | 2 | Nb | 60 | 30 | 4 |

## 3. PROCURED FILTER SAMPLES

We report hereafter the configurations of the procured filters for X-IFU development. The filters are divided in two main groups:

- **Large size filters** (section 3.1, 3.2, 3.3) Ti coated thick polypropylene stretched foil (~ 700 nm thick) replacing the 45 nm thick polyimide film to test the frame and mesh design (SS AISI 304, Nb) under static and dynamic loads. The meshes and the sizes of such filter samples are representative of the currently investigated TF but with different membrane materials.

- **Small size filters** (section 3.4) with Al coated thin polyimide film supported by Au plated SS meshes to test the thin foils under static and dynamic load, to perform thermo-vacuum tests, and X-ray spectroscopy. The material and mesh design of such filter samples are representative of the currently investigated X-IFU TF operating at 300 K, 100 K, 30 K, and 2 K but have smaller size (diameter = 30 mm).

### 3.1 ATHENA X-IFU Pre-Assessment Filter representative of TF300, TF100, TF30

Ti coated polypropylene stretched foil with thickness < 1 µm, attached to a SS AISI 304 structural supporting mesh, mounted on a 100 mm ID two parts aluminum frame (figures 2-3). The mesh and the Ti coating are in good electrical contact with the frame.

- **Name: ATHENA-01-03-15-A4 Rev. D101 (2 Ea)**
- **I.D.**: 100 mm (Thermal Filter TF300)
- **Film**: ~ 600 nm thick polypropylene stretched foil (BASF Novolen 1302L) with ~ 40 nm thick Ti coating supplied by UNIPA/INAF-OAPA.
- **Structural supporting mesh**: SS AISI 304, honeycomb, pitch size 5.0 mm, mesh bar thickness 130 µm, mesh bar width 65 µm, supplied by Luxel. Nominal transmission 97.4 %.
- **Frame**: two parts style Aluminum alloy 6061 anticorodal frame with 100 mm ID and four through holes plus two threaded holes to attach a protecting cover while transferring and mounting the filter. Frame supplied by UNIPA/INAF-OAPA according to drawing ATHENA-01-03_D100_X-IFU_28_12_2016.

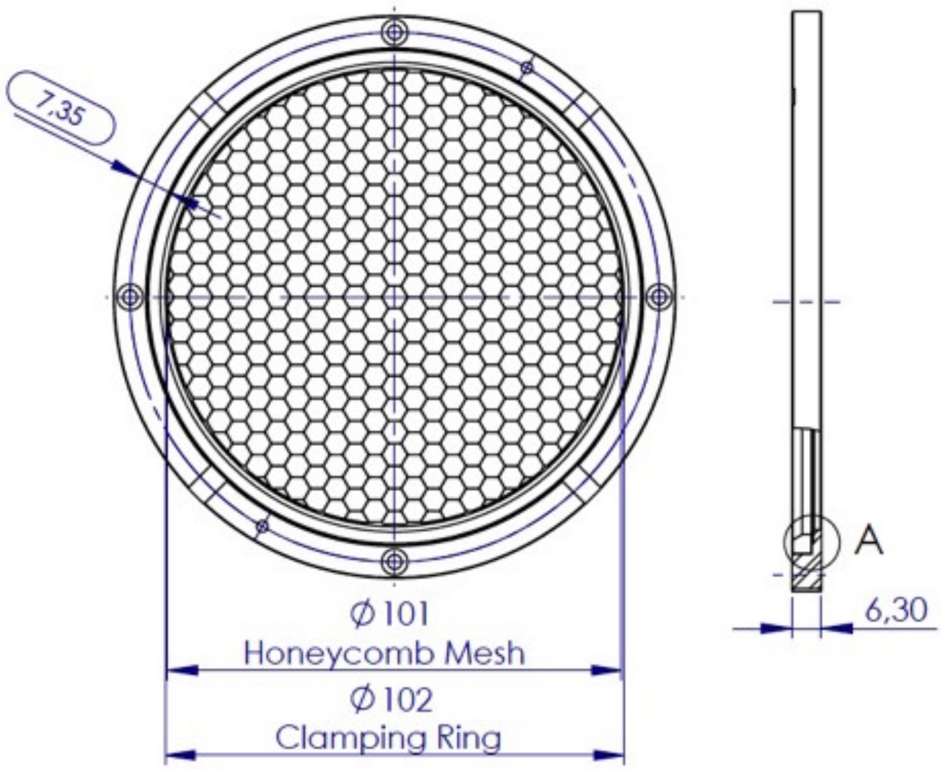



**Figure 2.** X-IFU full size sample partially representative of TF30, TF100, TF300.

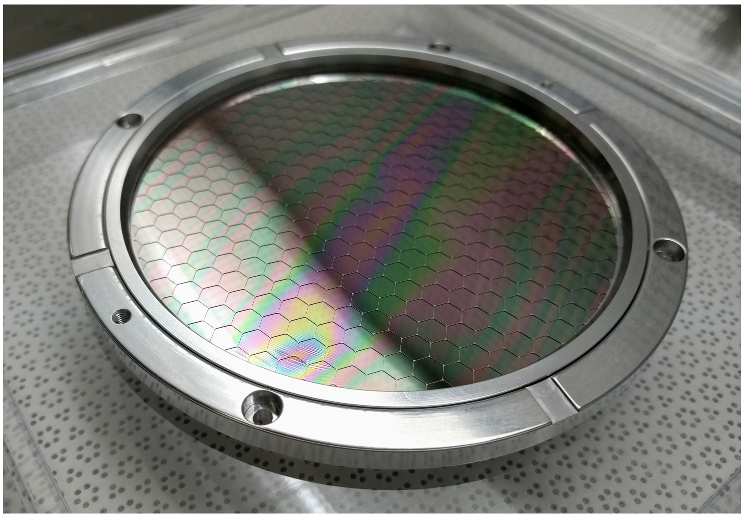


**Figure 3.** ATHENA X-IFU "dummy" Pre-Assessment Filter with inner diameter 100 mm.

### 3.2 ATHENA X-IFU Pre-Assessment Filter representative of TF2

Ti coated polypropylene stretched foil with thickness < 1 µm, attached to a SS AISI 304 structural supporting mesh, mounted on a 56 mm ID two parts aluminum frame (figures 4-5). The mesh and the Ti coating are in good electrical contact with the frame.

- **Name: ATHENA-01-03-11-A4 Rev. D57 (2 Ea)**
- **I.D**.: 56 mm (Thermal Filter TF0)
- **Film:** ~ 600 nm thick polypropylene stretched foil (BASF Novolen 1302L) with ~ 40 nm thick Ti coating supplied by UNIPA/INAF-OAPA.
- **Structural supporting mesh:** SS Aisi 304, honeycomb, pitch size 2.0 mm, mesh bar thickness 60 µm, mesh bar width 30 µm, supplied by Luxel. Nominal transmission 97% supplied by Luxel.
- **Frame:** two parts style Aluminum alloy 6061 anticorodal frame with 56 mm ID and four through holes plus two threaded holes to attach a protecting cover while transferring and mounting the filter. Frame supplied by UNIPA/INAF-OAPA according to drawing X_IFU_FILTER_ATHENA-01-03_D56.

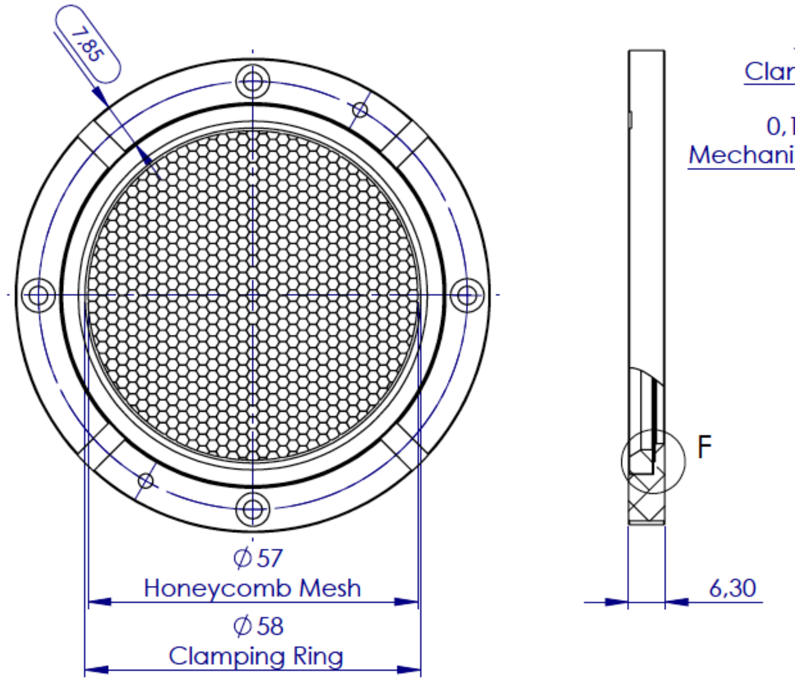



**Figure 4.** X-IFU full size sample partially representative of TF0 and TF2.

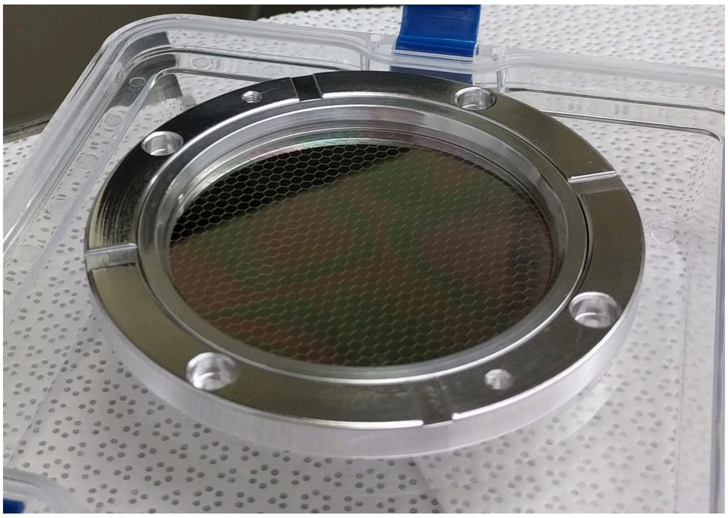


**Figure 5.** ATHENA X-IFU "dummy" Pre-Assessment Filter with inner diameter 56 mm.

### 3.3 ATHENA X-IFU Pre-Assessment Filter Exception Nb representative of TF0

Ti coated Polypropylene stretched foil with thickness < 1 µm, attached to a Nb structural supporting mesh, mounted on a 56 mm ID two parts aluminum frame. The mesh and the Ti coating are in good electrical contact with the frame.

- **Name: ATHENA-01-03-11 Rev A4-Exception Nb (2 Ea)**

- **I.D**.:56 mm (Thermal Filter TF0)
- **Film:** ~ 600 nm thick polypropylene stretched foil (BASF Novolen 1302L) with ~ 40 nm thick Ti coating supplied by UNIPA/INAF-OAPA.
- **Structural supporting mesh:** Nb, honeycomb, pitch size 2.0 mm, mesh bar thickness 50 µm, mesh bar width 30 µm, supplied by Luxel. Nominal transmission 97% supplied by Luxel.
- **Frame:** two parts style Aluminum alloy 6061 anticorodal frame with 56 mm ID and four through holes plus two threaded holes to attach a protecting cover while transferring and mounting the filter. Frame supplied by UNIPA/INAF-OAPA according to drawing X_IFU_FILTER_ATHENA-01-03_D56.

### 3.4 ATHENA X-IFU small samples

The filter consists of Al coated Polyimide film attached to Au plated SS AISI 304 structural supporting mesh, mounted on an a TF130 standard LUXEL (figure 6) two parts SS AISI 304 frame. The mesh and the Al coating are in good electrical contact with the frame.

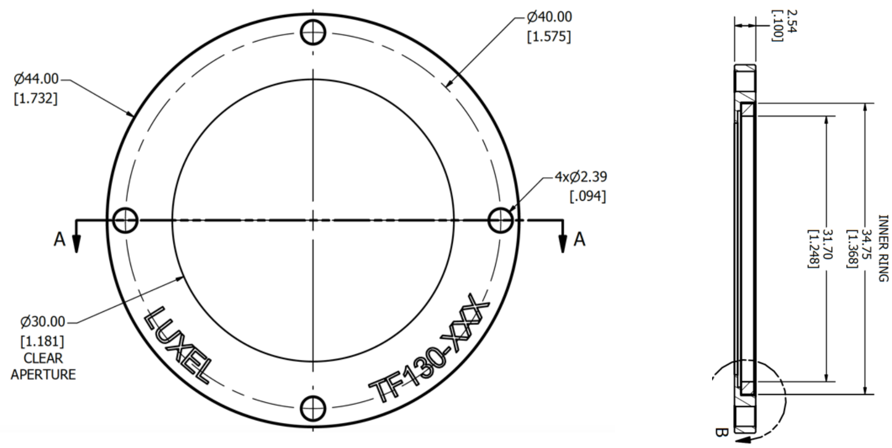



**Figure 6**. TF130 LUXEL standard frame used to mount filter samples partially representative of the thermal filters.

#### 3.4.1 TF130 with Coarse Mesh representative of TF300, TF100, and TF30

- **Name: TF130-071 TF130-072 (figure 7)**
- **I.D**.:30 mm
- **Film:** 45 nm thick LUXFilm® Polyimide / 30 nm thick aluminum supplied by Luxel.
- **Structural supporting mesh:** Ni/Au Plated 304 Stainless Steel, honeycomb mesh, pitch size 5.0 mm, mesh bar thickness 130 µm, mesh bar width 65 µm, supplied by Luxel. A 5 µm thick Au coating on each surface is applied to the mesh bringing the actual mesh bar thickness to 140 µm, and the mesh bar width to 75 µm supplied by Luxel. Nominal plated mesh transmission 97%.
- **Frame:** two parts style ASI 304 SS frame TF130-30.0-SS supplied by Luxel, machined according to drawing TF130S_Luxel.pdf.

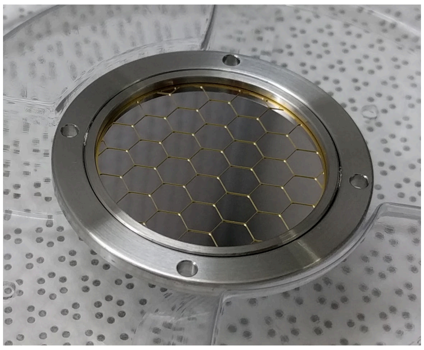


**Figure 7**. TF130 Coarse mesh partially representative of TF300, TF100, TF30.

#### 3.4.2 TF130 with Fine Mesh representative of TF2 and TF0.

- **Name: TF130-069 TF130-070 (figure 8)**
- **I.D**.:30 mm
- **Film:** 45 nm thick LUXFilm® Polyimide / 30 nm thick aluminum supplied by Luxel.
- **Structural supporting mesh:** Ni/Au Plated 304 Stainless Steel, honeycomb mesh, pitch size 2.0 mm, mesh bar thickness 60 µm, mesh bar width 30 µm, supplied by Luxel. A 5 µm thick Au coating on each surface is applied to the mesh bringing the actual mesh bar thickness to 70 µm, and the mesh bar width to 40 µm supplied by Luxel. Nominal plated mesh transmission 96%.
- **Frame:** two parts style ASI 304 SS frame TF130-30.0-SS supplied by Luxel, machined according to drawing TF130S_Luxel.pdf.

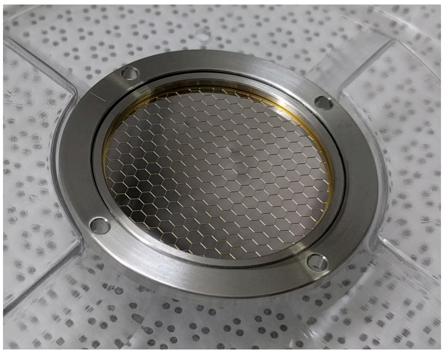


**Figure 8**. TF130 Fine mesh partially representative of TF2, TF0.

# 4. EXPERIMENTAL CAMPAIGNS

## 4.1 Acoustic Vibration Tests

The acoustic tests described in this document, performed on partially representative filters of the X-IFU detector on-board ATHENA, are part of the ongoing Phase-A Technology Development Activities. The acoustic vibration tests were performed AT AGH University of Science and Technology in Krakow.

Although the current baseline for the X-IFU detector is to launch the cryostat in vacuum, the option of launching in atmospheric pressure or moderate vacuum is under evaluation. For this reason, we are investigating by measurements and simulations whether the thermal filters can withstand a launch under acoustic load. As part of this investigation, we will mount a set of partially representative X-IFU TF inside a vacuum tight box and expose them to the acoustic load at different pressure levels, namely 10 mbar, 100 mbar and 1000 mbar. The acoustic tests have been performed in parallel to an acoustic test campaign performed on filter samples of the ATHENA Wide Field Imager detector.

At present, the acoustic load levels the filters must survive during the Athena launch are not available since the environment and mechanical systems the filter will be mounted in are not yet fully defined. The acoustic noise spectrum proposed for the test campaign has been derived from Req. # 15 in APPENDIX 1 to the ESA ITT AO/1-8786 (Table 2).

**Table 2 –** Acoustic Noise Spectrum inside the Ariane 5 Cargo during launch.

| Octave centre frequency [Hz] | Limit level [db] (reference: 0db = 2e-5 Pa) |
|---|---|
| 31.5 | 128 |
| 63 | 131 |
| 125 | 136 |
| 250 | 133 |
| 500 | 129 |
| 1000 | 123 |
| 2000 | 116 |
| OASPL (20-2828Hz) | 139.5 |

The reverberation chamber is set-up to simulate the sound spectrum of the Arianne V cargo. A few big speakers are positioned inside the reverberation chamber (figure 9).

**Figure 9.** Test equipment inside the AGH reverberation chamber. The plastic tent covers the filter wheel mock-up used to test WFI filters.

The X-IFU filters are mounted inside the aluminum box with plexiglass cover (Figure 10) inside a clean room class ISO7 of the “Academic Center of Material and Nanotechnologies” and is then hand carried outside, loaded onto the car and transported to the acoustic lab located in a different building.

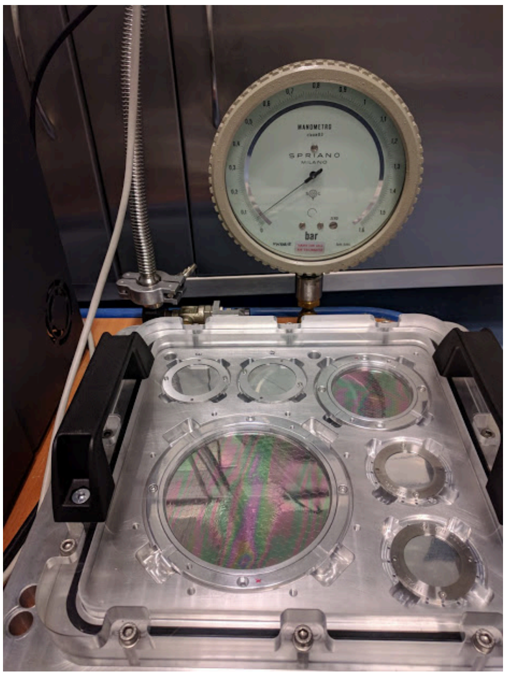



**Figure 10.** Aluminum box with plexiglass cover used to test the X-IFU test filters

in the reverberation chamber under controlled pressure.

All filters partially representative of the X-IFU TF and listed in the previous section have been tested under Ariane 5 launch acoustic pressure at 10 mbar, 100 mbar and 1000 mbar and have survived the tests. Although the chamber hosting the filters is not representative of the environment inside the cryostat where the filters will be kept at launch, this preliminary test is suggestive that the option of launching the cryostat in moderate pressure can be considered for further investigation.

Table 3 shows the measured difference between the Sound Pressure Level (SPL) inside the box containing the X-IFU filter samples and the reference SPL in the reverberation chamber at different SPL levels. AS shown the SPL is higher in the box than outside at low frequencies while it is lower at high frequencies.

**Table 3 –** Difference between the Sound Pressure Level inside and outside the box at various acoustic loads as a function of frequency.

| Frequency | SPL = 110 dB @ 125 Hz | SPL = 131 dB @ 125 Hz | SPL = 140 dB @ 125 Hz |
|---|---|---|---|
| 31,5 Hz | 3,1 | 2,8 | 2,3 |
| 63,0 Hz | 6,7 | 4,6 | 2,7 |
| 125 Hz | 6,9 | 2,3 | -0,8 |
| 250 Hz | -9,4 | -10,6 | -11,2 |
| 500 Hz | -14,3 | -14,4 | -14,5 |
| 1000 Hz | -10,3 | -11,0 | -11,7 |
| 2000 Hz | -9,7 | -11,6 | -11,8 |

## 4.2 Vibration Tests

We report hereafter some results from the vibration test program performed at CSL (Centre Spatial de Liege) and at MPE (Max Planck Institute for Extraterrestrial Physics) on partially representative filter samples of the ATHENA X-IFU detectors. In particular, the large filters were tested at CSL while the smaller filters were tested at MPE.
At present, no information about load levels the filters must survive during the Athena launch are available. The reference vibration load levels adopted in the tests have been derived from Req. # 14 in APPENDIX 1 to the ESA ITT AO/1-8786 (Table 4).

**Table 4.** Applied Reference Vibration Levels

**Sine Vibration Ref. Level**
25.0g (0-peak), sweep rate = 2 Oct/min

| F1 (Hz) | F2 (Hz) | Level |
|---|---|---|
| 5 | 25.0 | 9.9 mm (0-peak) |
| 24.1 | 26.2 | 1.5 m/s (0-peak) |
| 26.02 | 100 | 25.0g (0-peak) |

**Random Vibration Ref. Level**
16.9g RMS, duration = 150 s

| F1 (Hz) | F2 (Hz) | PSD |
|---|---|---|
| 20 | 100 | 3.0 dB/oct |
| 100 | 300 | 0.5 $g^2$/Hz |
| 400 | 2000 | -5.0 dB/oct |

Each filter sample is subject to more tests under increasing load levels. Just the final load level (the highest one) has duration consistent with space standards. Lower levels have shorter duration of 30 s in order to reduce the risk of fatigue failure.

### 4.2.2 Vibration tests at CSL

Sine and random vibration tests were carried out using the shaker model 4522 LX at the Centre Spatial de Liege (Belgium) on March 27-30, 2017. The test laboratory is a large size class 10.000 cleanroom. The shaker is mounted inside a class 100 environment. The X-IFU filters were tested in vacuum. Both out of plane and in-plane tests were carried out.

On the basis of the current design, the real flight filters, from the structural point of view, should consist in a very thin polyimide membrane and a reinforcing metallic mesh connected to a metallic frame by adhesive. In this first campaign the polyimide film was replaced by a thicker polypropylene membrane. So, current dynamic tests concern just the metallic mesh and the frames. The polypropylene membrane used for these tests is 600 nm thick, while the real polyimide film should be 10 times thinner in X-IFU filters. If we consider the assembly composed by mesh + film we note that by using polypropylene film instead of polyimide the membrane stiffness changes by few per thousand while the areal density changes by few per cent. So very small impact on metallic mesh behavior (deformed shape and stresses) is expected by replacing the thin polyimide with the thicker polypropylene.
Performed vibration tests are not qualification tests but development tests, to support the filter design. Tested prototypes partially represent the current design, which can still undergo significant changes before adoption.

The tested samples are:

- ATHENA X-IFU “dummy” Pre-Assessment Filter described in section 3.1.
- ATHENA X-IFU “dummy” Pre-Assessment Filter described in section 3.2.

A proper fixture (figure 11) was prepared to interface the filter to the shaker expander. It consists of an Al alloy plate allocating:

- holes for screwed connection to the shaker expander;
- holes to connect the filters by screw;
- holes to connect an upper cover (Al cover or Plexiglass one);
- vacuum seal gasket and vacuum valve.

Three control accelerometers were used on the test plate, while since filters are extremely light and delicate items accelerometer could not be allocated on the filters.

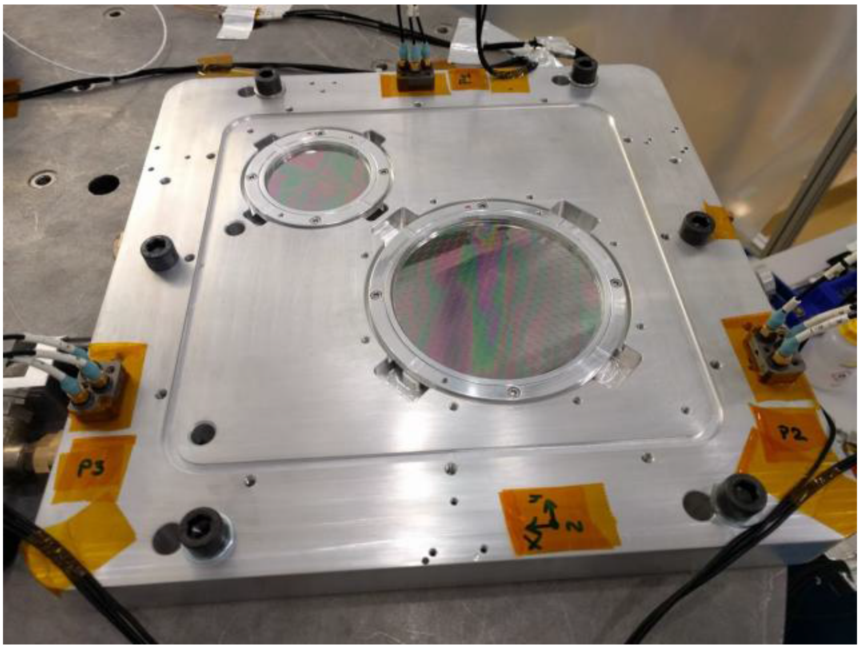



**Figure 11**. Two “dummy” X-IFU filters mounted in the fixtures.

Almost 40 test runs were carried out during the four days @CSL. Here we do not enter in a detailed description of each test run. We will simply provide main information to understand testing purpose and to properly identify the accelerometers location.

Tests can be divided in four main sessions:

- Fixture tests to verify that the fixtures used to connect filters to the shaker expander do not modify significantly the vibration input transmitted to the filters.
- Frame tests. Mounting accelerometers on the filter frames, during filter tests, was impossible or at least not advisable. So some dedicated test sessions on dummy frames completely alike the real ones but without filters (neither mesh nor film) were carried out.
- Filter tests under increasing loads until reference levels are reached (sinusoidal loads and random vibrations).
- Filter tests for increased load levels. Since all filters survived to the nominal loads without any macroscopic failure, higher load levels were applied to explore the existing margins of the metallic mesh strength.

Both the X-IFU dummy filters (metallic meshes + dummy films) have survived lateral vibration levels according to Ariane 5 launch reference specifications (Table 4) and axial vibration levels increased by +10g 0-peak sine load and + 3db random with respect to Ariane 5 launch reference specifications.

#### 4.2.2 Vibration tests at MPE

Sine, random, and shock vibration tests were carried out using the shaker model UD T-1000 at the Max-Planck-Institut fuer extraterrestrische Physik on November 6-11, 2017. Both out of plane and in-plane tests were carried out.

On the basis of the current design, the real flight filters, from the structural point of view, should consist in a very thin polyimide membrane and a reinforcing metallic mesh connected to a metallic frame by adhesive. In this campaign, some samples were produced in smaller sizes than the real ones.

The tested samples are

- ATHENA X-IFU “dummy” Pre-Assessment Filter TF0 Exception Nb (section 3.3)
- TF130-069 (section 3.4.2)
- TF130-072 (section 3.4.1)

X-IFU filters were tested in vacuum. To this purpose testing setup has a leak tight cover, to make vacuum. A vacuum level in the $10^{-2}$ range (TBC) is deemed sufficient for test purpose. Filters are extremely light and delicate items. So, the usual monitoring of the answer to the applied loads by accelerometer placed directly on the tested item is not possible. Accelerometers are envisaged just on the plate.

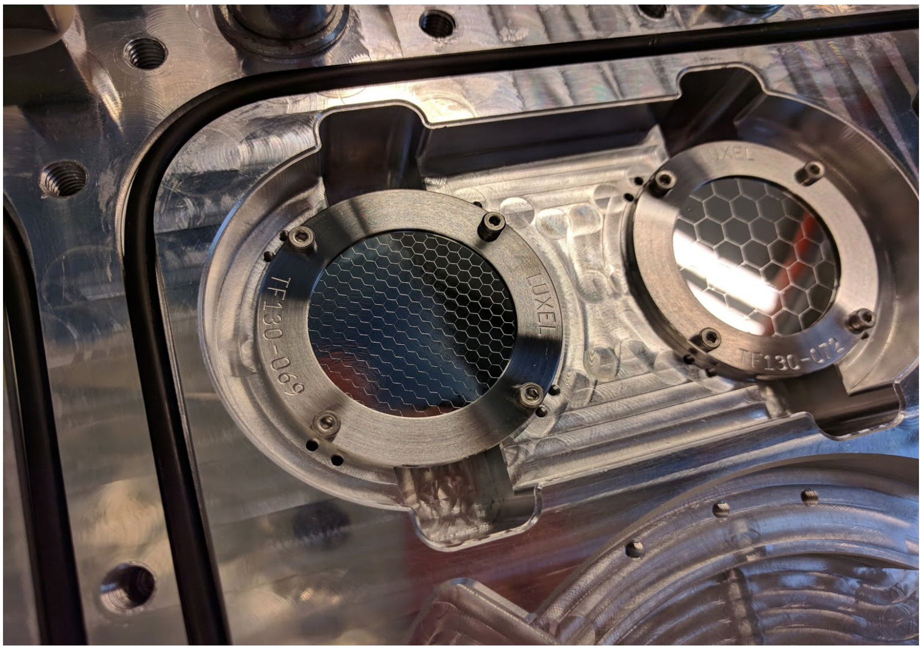



**Figure 12**. Two TF130 X-IFU mounted in the fixtures.

All tested X-IFU filter samples have survived lateral vibration levels according to Ariane 5 launch reference specifications and axial vibration levels increased by +10g 0-peak sine load and + 3dB random load. Filter have also survived shock tests in axial direction (the most dangerous one) according to Req. # 17 in APPENDIX 1 to the ESA ITT AO/1-8786 (Table 5) with the exception of the maximum frequency which, due to technical limitations of the shaker, was set to 3000 Hz.

**Table 4.** Shock test qualification level (Axial/lateral, Q = 10)

| Frequency (Hz) | SRS (g) |
|---|---|
| 100 | 20 |
| 1000 | 400 |
| 10000 | 400 |

### 4.3 Thermo-Vacuum

The first campaign of Thermo-Vacuum tests was performed using the cryostat of the LIFE facility at INAF-OAPA (Palermo). The sample holder was designed to accommodate two filters (TF130 LUXEL type) simultaneously (figure 13).

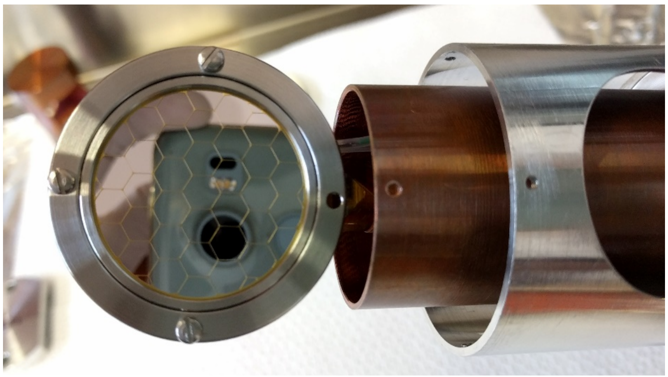


**Figure 13**. A TF130 sample in the sample holder.

Tests were performed in a very high vacuum (VHV) environment (~ $1.2 \cdot 10^{-9}$ mbar).
The tested samples are:

- TF130-070 (section 3.4.2)
- TF130-071 (section 3.4.1)

The thermal cycles parameters are listed below:

- 300 K → 12 K → 300 K @ 3 K/min
- 20 min. hold time at 12 K and 300 K

For each sample 10 cycles were completed in June 1-9, 2017. Images of the investigated samples were acquired with a high-resolution photographic scanner before and after the first cycle, and at the end of the last cycle. No evident visible damage or alteration was detected.

### 4.4 Trade-off Analysis

The current investigated X-IFU TF design differs from the baseline design:

1. thinner total layer of polyimide (225 nm vs. 280 nm);
2. thinner total layer of aluminum (150 nm vs. 210 nm);

3. use of metal meshes in place of polyimide meshes.

While the first two points allow the investigated design to be more performing with respect to the baseline at low energies; the use of metal meshes, driven by the need to provide mechanical robustness, RF attenuation, and good thermal conductance, implies a transmission at high energy currently below the requirements (Figure 14).

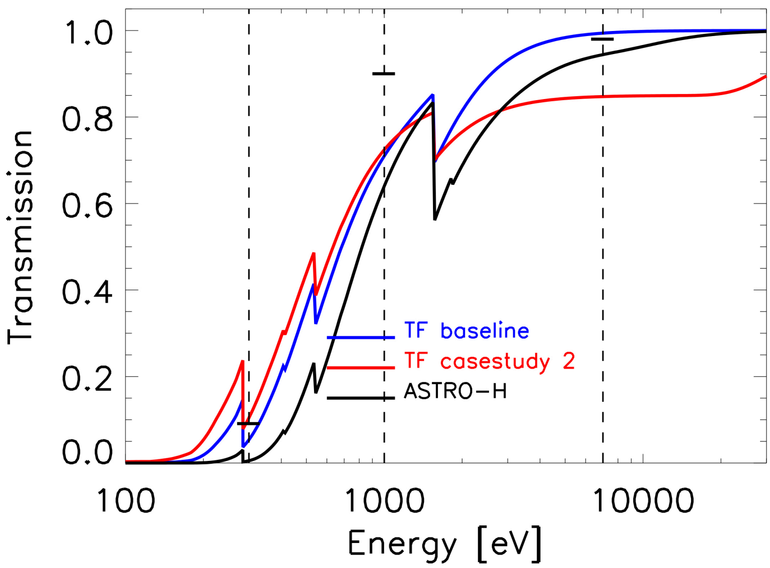



**Figure 14.** X-ray transmissivity of the complete set of thermal filters currently studied (red line) compared to the basic design described in the original proposal of ATHENA (blue line) and to the filters made for ASTRO-H (black line).

The positive results from mechanical tests, showing that the current designed meshes can survive the Ariane 5 launch vibration load, suggest to perform new structural modelling to try to optimize the design of the meshes in order to increase the overall transmission. In addition, EM modeling and measurements will be performed to verify the RF attenuation level of thin Al layers and thus try to release a bit the attenuation requirements on the meshes. Different materials (both meshes and foils) as well as geometries will be further investigated before consolidating the TF design and procuring representative filter samples to demonstrate the TRL 5 before the adoption of Athena by ESA.

Table 5 shows a first hypothesis of a new configuration of the supporting meshes that would allow to recover almost 5% of transmissivity in X-rays at energies greater than 2 keV. The meshes with reduced blocking factors are currently under investigation by structural analysis and modelling.

**Table 5.** Main features of the supporting mesh of the five X-IFU thermal filters optimized to increase X-ray transmission at high energies.

| Filter | T [K] | Z [mm] | D [mm] | Mesh pitch [mm] | Mesh material | Wire thick. [µm] | Wire width [µm] | Plating thick. [µm] | BF (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| TF300 | 320 | 240 | 101 | 5 | SS/Ag | 80 | 40 | 10 | 2.4 | AC |
| TF100 | 100 | 210 | 90 | 5 | SS/Au | 80 | 40 | 5 | 2.0 | AC |
| TF30 | 30 | 180 | 79 | 5 | SS/Au | 80 | 40 | 5 | 2.0 | AC |
| TF2 | 2 | 130 | 60 | 2 | SS/Au | 40 | 20 | 5 | 3.0 | FPA |
| TF0 | 0.05 | 10 | 25 | 2 | Nb | 40 | 20 | - | 2.0 | FPA |

## 5. PUBLICATIONS

1. The focal plane assembly for the Athena X-ray Integral Field Unit instrument - Brian Jackson et al., 2016, SPIE 9905-2I.
2. Surface investigation and aluminum oxide estimation on test filters for the ATHENA X-IFU and WFI detectors - Luisa Sciortino et al., 2016, SPIE 9905-66.
3. Temperature effects on the performances of the ATHENA X-IFU thermal filters - Marco Barbera et al., 2016, SPIE 9905-60.
4. The Filter Wheel and Filters development for the X-IFU instruments on-board Athena - Enrico Bozzo et al., 2016, SPIE 9905-61.
5. The Athena X-ray Integral Field Unit (X-IFU) – Didier Barret et al., 2016, SPIE 9905-2F.
6. The Athena X-ray Integral Field Unit (X-IFU), Francois Pajot et al., 2017, JLTP, published on-line (https://doi.org/10.1007/s10909-018-1904-5)
7. Characterization Tests of Thermal Filters for the ATHENA mission X-IFU Low Temperature Detector, Marco Barbera et al., 2018, JLTP in press.
8. A temperature dependent X-ray absorption characterization of test filters for the ATHENA mission X-IFU instrument, Luisa Sciortino et al., 2018, JLTP in press.