# Calibration of the AXAF-HRC UV/Ion shields at Osservatorio Astronomico di Palermo G.S. Vaiana: II - X-ray transmission measurements

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## ABSTRACT

X-ray transmission measurements have been conducted at the XACT facility on baseline design AXAF-HRC UV/Ion shield using an electron impact X-ray source, a transmission grating monochromator and gas flow proportional counters. Transmission has been measured at several energies in the range 0.1-2.0 keV with and without the transmission grating monochromator. It turns out that the monochromator enormously improves the measurement accuracy. UV measurements conducted by us on the same shield and reported elsewhere showed an unexpectedly high UV transmission which led to a redesign of the UV/Ion shields. Calibration of the new shields, based on different materials, is still in progress. In this paper we outline the calibration procedure and the data analysis technique, and report transmission results on the baseline design shield.

## 1 INTRODUCTION

The baseline design of the AXAF-HRC[7,6] UV/Ion shields was based on an unsupported Lexan membrane 6000 Å and 2500 Å thick for the imaging and for the spectroscopic detector, respectively, coated on both sides with aluminum. The sample measured in this work is a shield for the imaging detector, manufactured by Luxel Corp. It was a flight candidate before measurements conducted by us at the XACT facility[1,3] showed that interference effects and aluminum oxidation enhance transmission at UV wavelengths above 2300 Å to such an extent that a redesign of the shield was necessary. New shields, based on Polyimide membranes, are now under measurement. For this reason this paper, which was initially meant to report final calibration results on the flight shields, reports instead results on X-ray transmission measurements conducted on the Lexan baseline design obsolete shield. Nevertheless it provides useful information on the measurement techniques adopted and shows how the use of a very simple monochromator based on an X-ray transmission grating enormously improves measurement accuracy.

The instrumentation set up for the measurements is described in another paper.[4] Here we concentrate on the measurements, the data analysis and the results.

## 2 MEASUREMENTS

Measurements were conducted at the XACT facility adopting two different setup:

In a first set of measurements two gas flow proportional counters have been used as detectors with no X-ray transmission grating monochromator. Small portions of the UV/Ion shield ($15 \times 1.3 mm^2$) have been measured in nine different positions around the center of the UV/Ion shield (see figure 1).

The transmission grating monochromator[4] was then included in the beam line and the transmission at position 2 of figure 1 was measured with this new set up.

Horizontal and vertical scans of the UV/Ion shield were conducted to locate the borders of the shield. The center position was then computed. Position 5 in picture 1 was located on the shield center.

For each of the nine surveyed positions and the open position and for each anode, two Multi-Channel Analyzer (MCA) spectra were taken, one with each of the two detectors. One of the two detectors (normalization detector) was always used to monitor the X-ray beam during measurements in order to provide a reference for normalization, and therefore was never used with the UV/Ion shield in front. The other detector (measurement detector) was used with the shield in front or in the open position. The integration time of each spectrum has been chosen so to have at least 30000 counts in the line of interest and, in any case, more than 300 s.

In order to conduct measurements with the transmission grating monochromator the entrance slit together with the grating was placed in the beam, and aligned using a laser source. Different energies were selected moving the entrance slit and grating along the (vertical) dispersion direction, by means of a precision micrometer.

# 3 DATA REDUCTION

## 3.1 Isolating the Line Contribution

In order to isolate the contribution of the line of interest in the MCA spectra from contamination lines like carbon and continuum when no monochromator is used, we modeled the spectrum of the electron impact X-ray source including the fluorescent lines of the anode material plus a Bremsstrahlung continuum. Since the proportional counters used in our transmission measurements are detectors with moderate energy resolution ($\sim \Delta E/E \sim 45\%$ at 1 keV), in order to separate the contribution of the continuum from the fluorescent line(s) of interest, the expected MCA spectrum was modeled in terms of line contributions plus a continuum, and the parameters of the model estimated through a fitting procedure to the observed MCA spectrum.

The MCA spectrum of a monochromatic line has been modeled with a Prescott function[8]

$$S_L(m) \;=\; a\,[\frac{(p/m)^{3/4}}{\sqrt{4\pi p\; c}}]\; e^{[2\sqrt{\frac{p\;\;m}{c^2}}-\frac{p+m}{c}]} \tag{1}$$

where $p$ is the peak channel and $S_L(m)$ are the counts detected in the m-th channel. The amplitude parameter $a$ and the width parameter $c$ have been used as free parameters in the fit.

The MCA spectrum of the continuum ($S_C(m)$) has been modeled with a linear function

$$S_C(m) \;=\; b\,[m - m_{max}] \tag{2}$$

where $m_{max}$ is the channel corresponding to the maximum energy of impact electrons in the X-ray source. The amplitude parameter $b$ has been used as free parameter in the fit.

After some time of operation each anode in the X-ray source is polluted by carbon deposition and therefore the X-ray spectrum also contains the $K_\alpha$ fluorescent line of carbon. For this reason this line must be also taken into account in the fitting analysis, in measurements conducted with no monochromator.

Model parameters were then determined using a least $\chi^2$ fit. An example of this procedure is shown in Figure 2 were the fitting curve (dashed line) is superimposed to the MCA spectrum obtained with the Magnesium Oxide anode (solid line). Lines of Magnesium, Oxigen and contaminating Carbon are clearly visible.

In order to estimate the number of counts in the line of interest and its standard deviation, we have adopted a bootstrap technique. This consists in generating a large number ($> 100$) of set of parameters randomly extracted from normal distributions of the least Chi-Square parameters, and computing for each of this set of parameters the integration of the line of interest. Such computed integrations follow a distribution for which a mean and a standard deviation was calculated.

Once all spectra have been analyzed and the number of counts in the lines has been determined, the transmission of the filter at the energy of these lines has been calculated as follows. The count rate of the measurement detector with the filter mounted in front of the entrance window is divided by the count rate measured with the same detector without the filter. In order to take into account any variation of the source intensity with time, the count rates of the measurement detector are divided by the count rates of the normalization detector in the simultaneous integrations. The explicit expression used to calculate the filter transmission at each line is:

$$T_F = \frac{N2_M/N2_N}{N1_M/N1_N} \tag{3}$$

where $N1_M$ and $N1_N$ are the number of counts detected by the measurement and normalization counters during the measurement with no filter. $N2_M$ and $N2_N$ are the number of counts detected, during the second measurement, by the measurement detector plus filter, and by the normalization counter without filter, respectively. The integration time during each measurement is the same for both measurement and normalization counters and therefore cancels out in equation 3.

### 3.2 Fitting the Transmission Measurements

The transmission through a layer of a given material as a function of incident photon energy (E), can be written in this form:

$$T(E) = e^{-\frac{\mu}{\rho}\rho t} \tag{4}$$

where $\rho$ is the mass density of the absorbing material, $\mu$ is the linear attenuation coefficient, and $t$ is the thickness of the layer. The ratio $\frac{\mu}{\rho}$ is called the mass attenuation coefficient and, for a pure element, is related to the imaginary part of the atomic scattering factor $(f_2)$ by the expression

$$\frac{\mu}{\rho}(E) = 2r_e hcN_0 \frac{f_2}{A\ E} \tag{5}$$

where $r_e$ is the classical electron radius, $h$ is the Planck constant, c the speed of light, $N_0$ the Avogadro number, A the atomic mass of the element. If we substitute the proper constant values we obtain

$$\frac{\mu}{\rho}(E) = 4.2079\ 10^7\ \frac{f_2}{A\ E} \qquad [cm^2\ g^{-1}] \tag{6}$$

where E is in $eV$ and A is in atomic mass units.

The values of $f_2$ have been measured for 92 atomic elements by Henke et al.[5] for a large number of energies covering the range $10 - 10000\ eV$. Using the mass attenuation coefficients derived from the $f_2$ Henke values, it is possible to fit the measured transmission of the layer of given element to determine the quantity $\rho t$. If an independent measurement of the thickness of the layer or the mass density is available, this fitting allows the determination of the other parameter.

For compounds the mass attenuation coefficient is

$$\frac{\mu}{\rho} = \sum_i (\frac{\mu}{\rho})_i\ w_i \tag{7}$$

where $(\frac{\mu}{\rho})_i$ is the mass attenuation coefficient of element i, and $w_i$ is the fraction by weight of element i.

$$w_i = \frac{n_i\ A_i}{\sum_i n_i\ A_i} \tag{8}$$

where $n_i$ is the relative number of atoms of element i in the compound, and $A_i$ is the atomic weight of element i.

We have adopted this fitting procedure and have determined the linear density ($\rho\ t$) for both the plastic material and the aluminum coating.

# 4 RESULTS

Figure 3 and 4 show a plot of transmission measured at position 2, without and with the monochromator, respectively. The solid line is the best fit model. Note that Figure 4 includes a measurement at 575 eV (Cromium $L$ line) which is too faint to be reliably used without monochromator. Due to the low flux, the error bar of this measurements is large compared to other measurements in the same plot. Least Chi-Square parameters and relative 1 $\sigma$ uncertainties are reported in table 1. The thicknesses were computed assuming a density of 1.14 $g/cm^3$ for Lexan and 2.5 $g/cm^3$ for aluminum.

We note that results obtained without monochromator at different positions are consistent each other within the error, thus indicating that the UV/Ion shield is spatially uniform within the measurement accuracy. However, the derived thickness of both Lexan and Aluminum is larger than specified by the manufacturer. In addition, Figure 3 shows some discrepancy between the measured transmission and the model, and model parameters derived without monochromator agree with those derived with the monochromator only at 2 $\sigma$ level.

Results obtained with the monochromator are in excellent agreement with the best fit model (see Figure 4) and the derived thickness is much closer to manufacturer specifications ($6065 \pm 100$ Å Lexan, $705 \pm 50$ Å Aluminum, to be compared with results at position 2* in Table 1). The small discrepancy between measured and manufacturer specified Lexan thickness is probably due to the adopted value of density. Furthermore, transmission measurements conducted by us at BESSY Sinchrotron facility an a witness sample of the UV/Ion shield measured in this work[2] confirm our results obtained with the monochromator. Figure 5 shows, as a function of energy, the uncertainty on the transmission of the UV/Ion shield derived from measurements conducted with the monochromator, providing information on the accuracy that can be achieved with our measurements.

We interpret the discrepancy between measurements without and with the monochromator as due to the blending of different lines, possibly due to carbon contamination and oxidation of anodes. In measurements with no monochromator, contributions of different lines are not well separated by the poor energy resolution of the proportional counters. This interpretation is supported by the evidence that the discrepancy is systematic, and measurements conducted at different positions without the monochromator are consistent each other.

# 5 CONCLUSION

We have reported preliminary soft X-ray transmission measurements of a baseline design imaging HRC UV/Ion shield. Measurements were conducted using two different setup, one of which includes a transmission grating based X-ray monochromator. We demostrate that the usage of a monochromator enormously improves the quality of measurements, especially when anodes subject to oxidation are employed as targets in the X-ray source. The agreement between transmission measurements conducted with the monochromator and the transmission model is excellent. The best fit gives thicknesses of Lexan and Aluminum of 6600 $\AA \pm 100$ and 770 $\AA \pm 40$, respectively, assuming densities of 1.14 $g/cm^3$ and 2.5 $g/cm^3$ for Lexan and Aluminum, respectively. Figure 5 shows the error on transmission as a function of energy due to the uncertainties on the shield areal density evaluated from the measurements conducted with the transmission grating monochromator. This plot shows that very good accuracy on transmission can be obtained with the instrumental set-up which includes the monochromator.

# 6 REFERENCES


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# 7 TABLES AND FIGURES

| | Lexan | | Aluminum | |
|---|---|---|---|---|
| Position | $\rho\, T$ | $T$ | $\rho\, T$ | $T$ |
| 1 | 90 ±9 | 7900 ±800 | 20 ±1 | 780±50 |
| 2 | 90 ±3 | 7900 ±300 | 20.2±0.4 | 810±20 |
| 2* | 75 ±1 | 6600 ±100 | 19 ±1 | 770±40 |
| 3 | 91 ±3 | 8000 ±300 | 20.4±0.4 | 810±20 |
| 4 | 90 ±3 | 7900 ±300 | 20.2±0.4 | 810±20 |
| 5 | 92 ±3 | 8000 ±300 | 20.3±0.4 | 810±20 |
| 6 | 90 ±3 | 7900 ±300 | 20.7±0.4 | 830±20 |
| 7 | 90 ±3 | 7900 ±300 | 20.4±0.4 | 820±20 |
| 8 | 87 ±3 | 7600 ±300 | 20.7±0.4 | 830±20 |
| 9 | 88 ±3 | 7700 ±300 | 20.4±0.4 | 820±20 |

Table 1: Least Chi-Square fit results - 2*=with monochromator

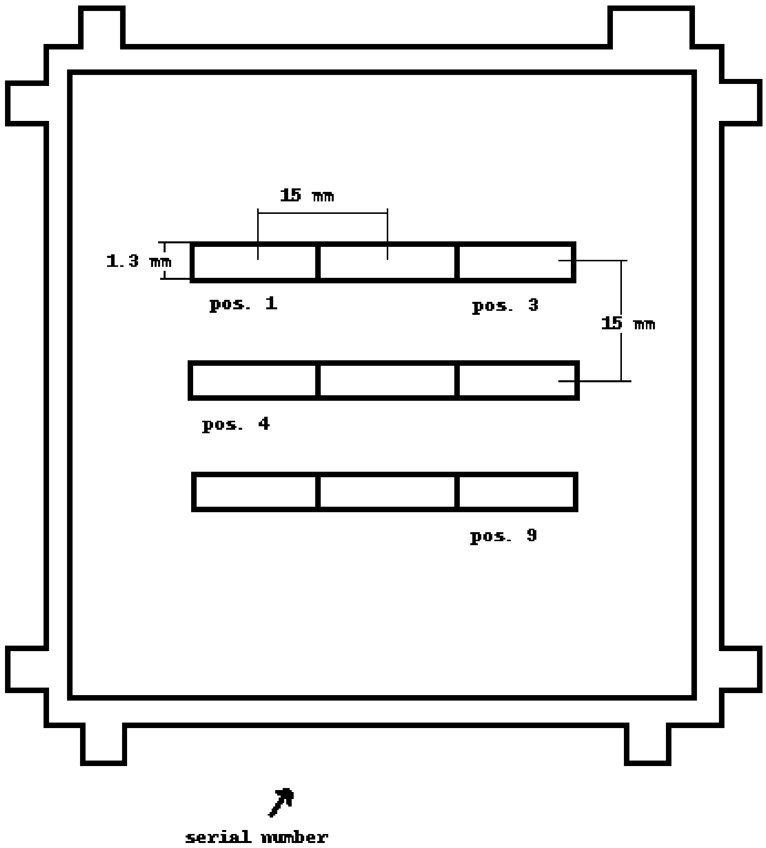


Figure 1: Scketch of the nine positions surveyed with no monochromator.

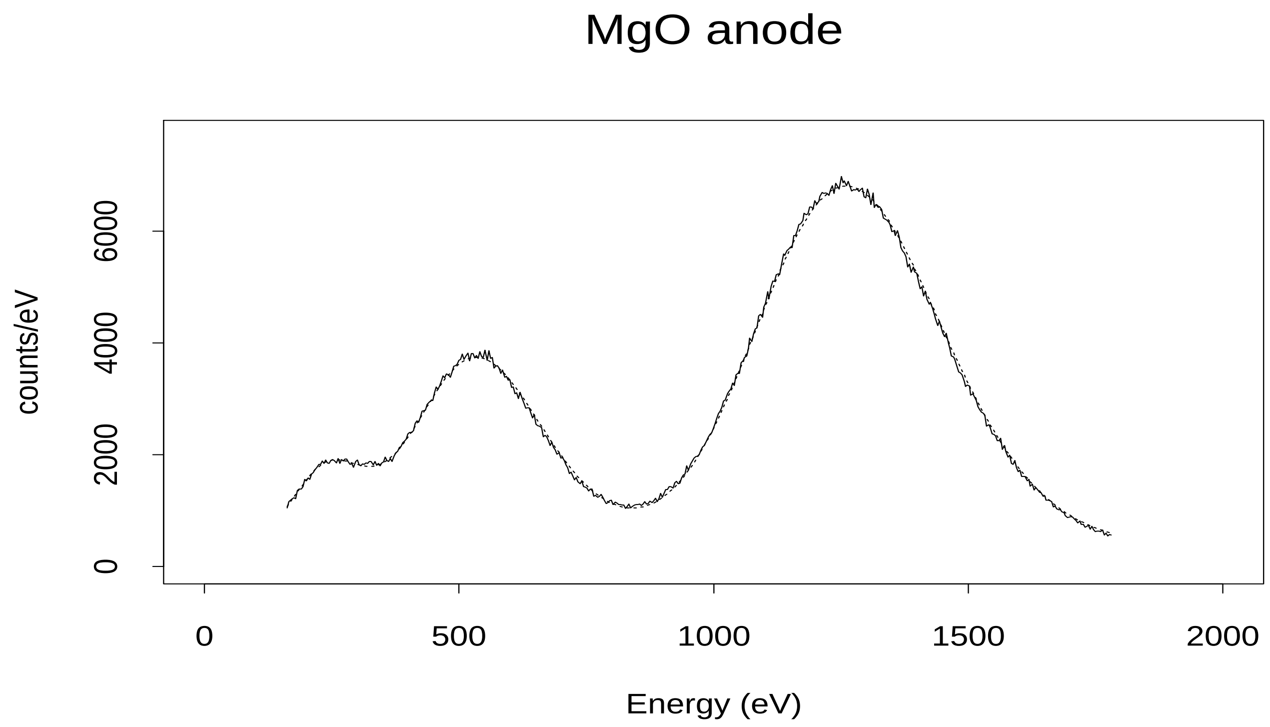


Figure 2: Multi Channel Analyzer spectrum of the X-ray source mounting a Magnesium anode with a deposition of Magnesium Oxide and an operating voltage of 2.5 kV. The gas flow proportional counter detectors were operated with P10 gas (10% Argon + 90% Methane) at 300 torr and HV=1.49 kV. The superimposed dashed line is a model spectrum including Carbon K line contribution at 277 eV (Prescott function), and continuum (linear function). See section 4 for details.

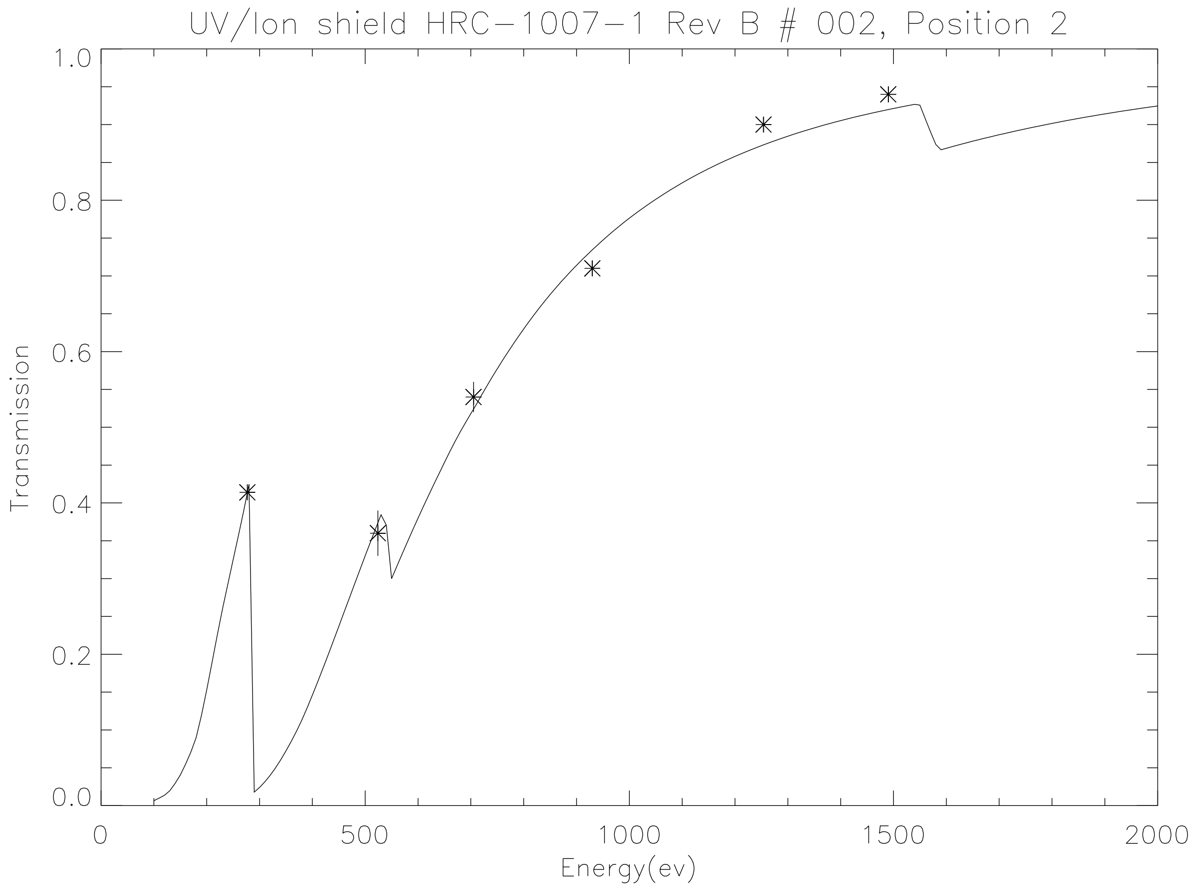


Figure 3: Transmission Measurements with 1 $\sigma$ uncertainties conducted with no monochromator on UV/Ion shield at position 2. The superimposed curve is the least Chi-Square fit.

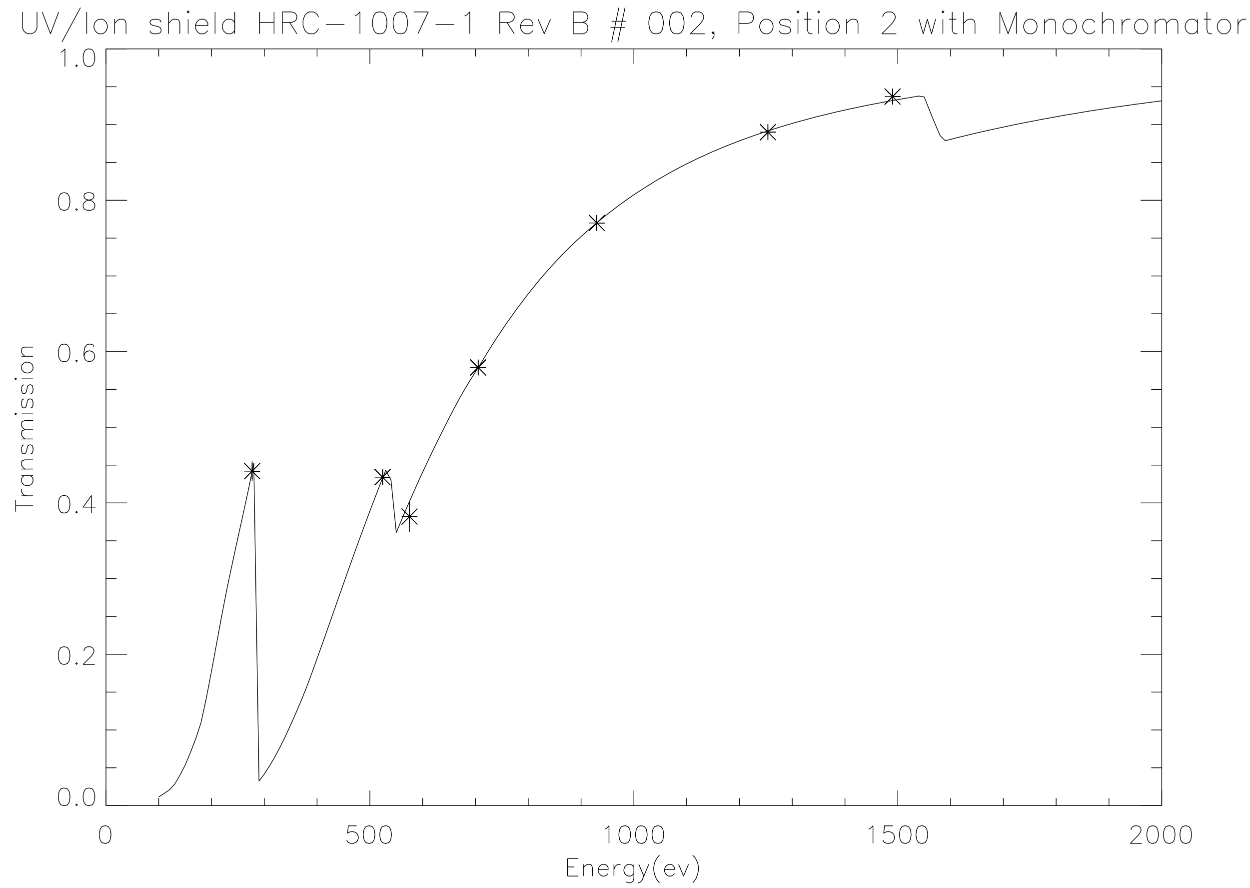


Figure 4: Transmission Measurements with 1 $\sigma$ uncertainties conducted with the transmission grating monochromator on UV/Ion shield Position 2. The superimposed curve is the least Chi-Square fit.

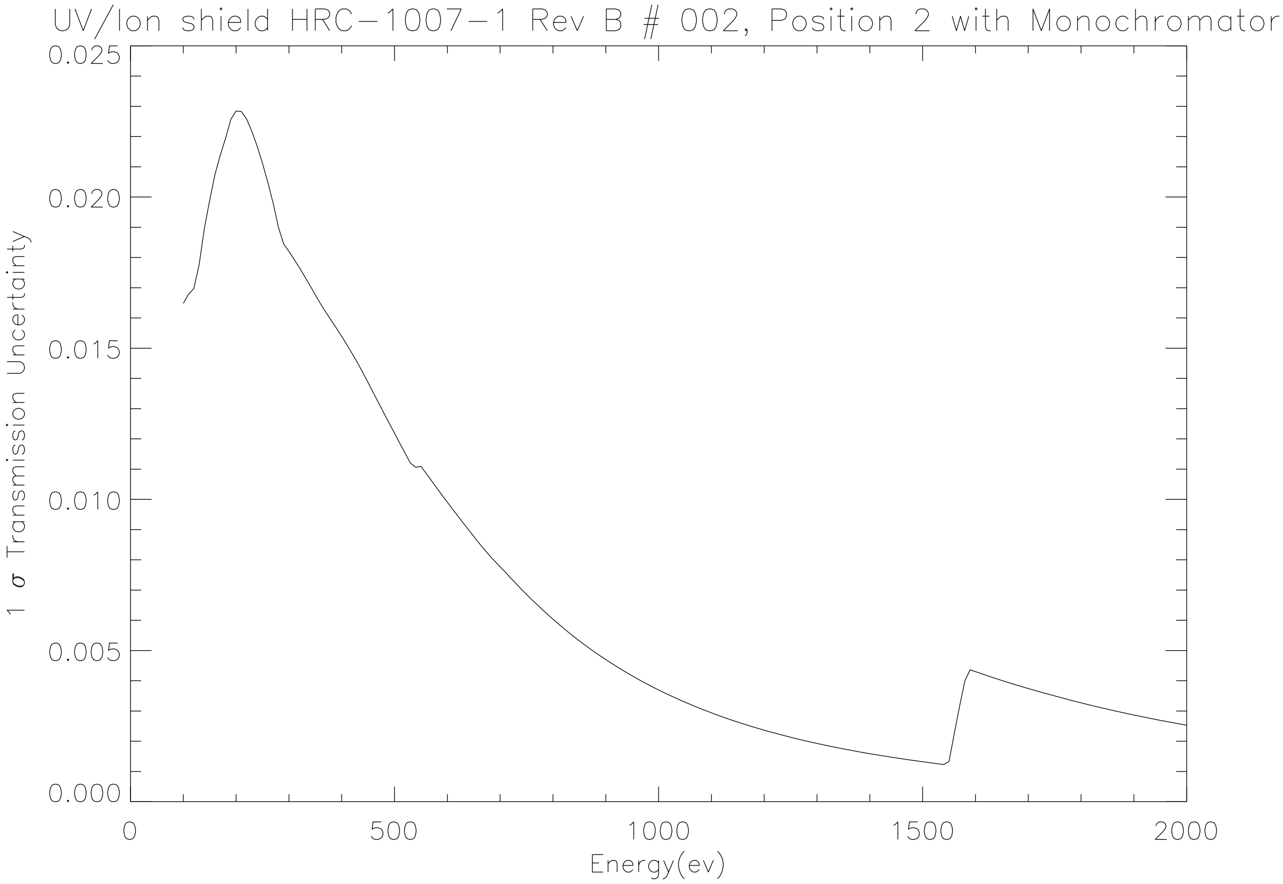


Figure 5: Transmission uncertainty as a function of energy due to the uncertainties on the shield areal density evaluated from the measurements conducted with the transmission grating monochromator.