Calibration of the HRC-I UV/Ion Shield

1 Introduction

The x-ray transmission characteristics of the flight HRC-I UV/Ion shield (S/N-004) are based on measurements carried out at both the SAO's HRC laboratory and at the Physikalish-Technische Bundensanstalt (PTB) radiometry laboratory of the BESSY 1 synchrotron in Berlin, Germany. The measurements were made using the two witness samples delivered along with the flight filter, which was manufactured by the Luxel Corporation of Friday Harbor, WA. Luxel physically measures the thickness of their foils with a high-quality profilometer manufactured by Tencor. Its mechanical stylus measures the step height across an edge in the material with a resolution of $\pm 5\AA$. When calibrated against a known standard, it has been their experience that it performs within the uncertainty of the standard, which is $\pm 17\AA$. We have found that Luxel's aluminum and polyimide thickness measurements agree with our derived thickness measurements of the constituent filter layers, within the statistical uncertainties. Figure 1 shows the nominal thickness values of the constituent layers of the HRC-I UV/Ion shield (UVIS-I).

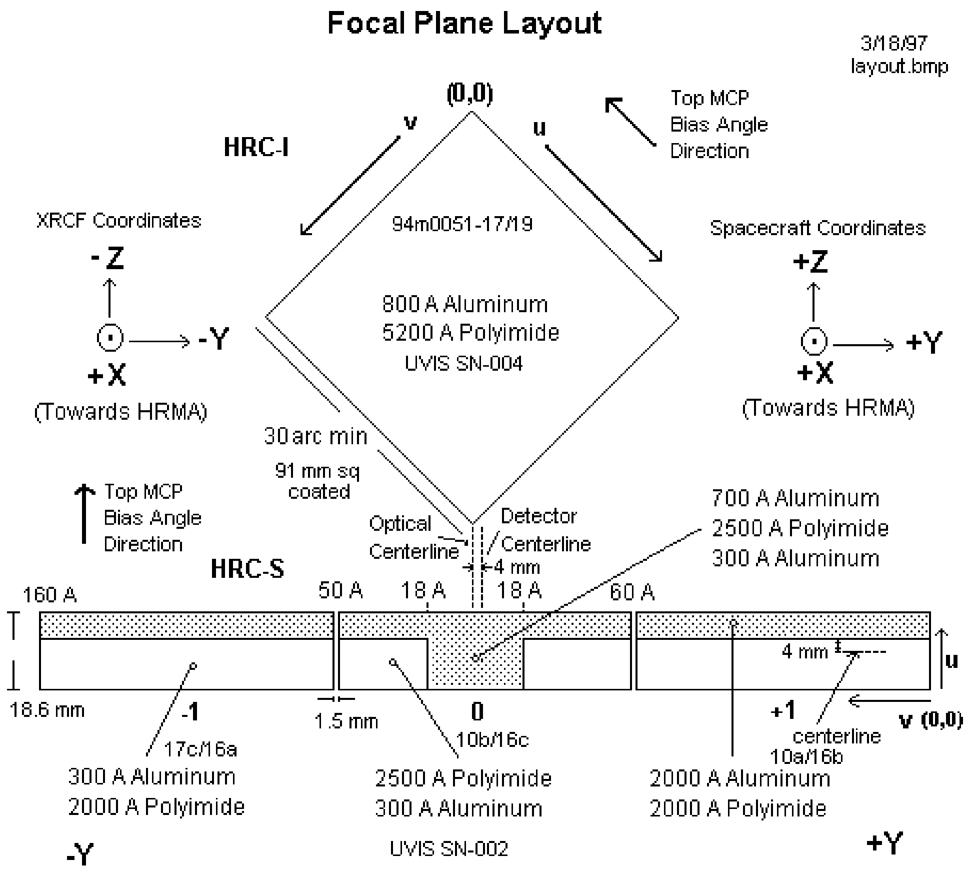

Figure 1: The material composition of the UVIS-I is shown above. The thicknesses are nominal. Where there is only a single side coated with aluminum, that side faces the High Resolution Mirror Assembly (HRMA) of Chandra. The figure also shows the relative orientation of the HRC-I and HRC-S in the instrument focal plane.

The pair of witness samples comes from the same filter production run as the associated flight filter, and are taken from different regions of the larger filter sheet. Those transmission measurements that were carried out on an identical witness sample (TF101-1174) at both facilities yielded statistically similar fits. We used this fact in developing our x-ray transmission model of the UVIS-I. A detailed account of our measurements was presented at the 1997 SPIE conference in San Diego, CA.[1] This report can be accessed through the HRC calibration web site at

http://hea-www.harvard.edu/HRC/calib/spie97.html.

1.1 SAO and BESSY Instrumental Setups

The SAO measurements to characterize the flight UVIS-I x-ray transmission were carried out on the witness samples (see table 1) using a McPherson model 248/310 G 1-meter diameter grazing incidence monochromator. It is equipped with a 1200 G/mm grating which has a $2^o5'$ blaze angle and a 5442Å blaze wavelength. This yields an operating range of 2.8 Å to 340.7 Å. The monochromator entrance and exit slits were set to a nominal 20 μm width to minimize contamination by the x-ray continuum. Figure 2 represents a typical monochromator beam scan to identify the fluorescent lines associated with the anode selected for use in the Manson model 2 single-anode soft x-ray source. In this case, the anode is titanium. The scan shows that the Ti L_α and L_η lines dominate over the continuum by about a factor of 10.

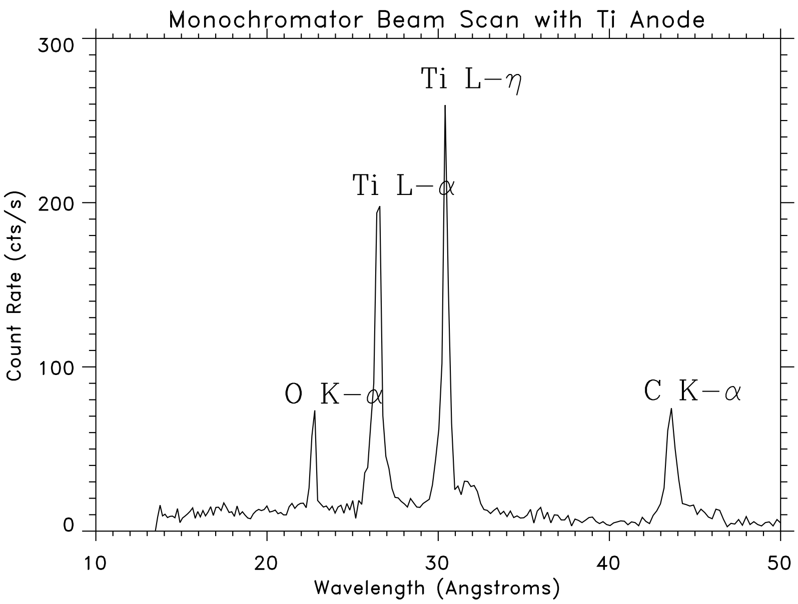

Figure 2: Example of a typical monochromator beam scan to identify the first order x-ray fluorescent lines associated with an anode. In this case, the anode is titanium. Note how the primary lines of interest, Ti L_α and L_η, dominate over the continuum.

When a fluorescent line is selected, the monochromator is adjusted to operate at its peak. The instrument is also equipped with a pair of filter wheels, each of which has enough holders to accommodate up to five witness samples. However, one holder of each wheel was intentionally left unoccupied so that x-ray spectra could be obtained without a filter in the x-ray detector beam path as part of the transmission measurement procedure. Spectra were acquired with a Manson model 851 gas-flow proportional counter equipped with a VYNS window, and which utilized methane as the fill gas.

The SAO experimental setup precluded any effort to perform spatial uniformity measurements on a given witness sample. Rather, each measurement represents an average transmission over a filter. However, we know from previous uniformity measurements of a flight candidate HRC-I UV/ion shield, that it was spatially uniform in transmission within 5% relative error at a spatial scale of 1 mm.[2]

The BESSY synchrotron measurements were conducted at station 11.31 of the Physikalish-Technische Bundensanstalt (PTB) radiometry laboratory. The beam-line includes an SX-700 type plane grating monochromator with a useful photon energy range of 60 - 2000 eV and spectral resolution ranging from $E/\Delta E = 2500$ at 100 eV to $E/\Delta E = 700$ at the Al-K edge. A test chamber (700 mm long, 600 mm in diameter) was provided with a vacuum-compatible micro-positioning system for the manipulation of witness samples and detectors. Two detectors were used: a GaP/Au Schottky-type photo-diode (Hamamatsu G1963) with a sensitive area of 4.6 mm$\times$4.6 mm; and a VALVO X913 BL channel electron multiplier (CEM). The photo-diode performs well and is actually used at all surveyed energies with the exception of the 283-300 eV range, where the CEM is more appropriate because of the low flux available in that region.

Of the two flight UVIS-I witness samples, only one (TF101-1174) was measured at the BESSY facility. It was mounted on a four-position fixture (one position left open) attached to a micro-positioning system allowing complete two dimensional scans of the sample. A 400 μm spot size was chosen as the best compromise between flux stability and spatial resolution. Table 2 describes the energy scans in detail.

Each individual measurement at a given energy is the average of 3 independent consecutive detector readings. If the readings are not consistent with each other to within 1%, the measurement is automatically repeated. Each measurement is normalized by the current of the beam in the storage ring. This procedure accounts for the time dependence of the beam, ensuring measurement stability at the 1% level over a time scale of 30 minutes. In order to ensure no significant drift between measurements at the open and sample positions, all of our measurement sets were taken over time scales shorter than 10 minutes.

The measurement technique described above ensures a statistical uncertainty within 1% at all energies. Stray light contribution in the monochromatic radiation between 1.0 and 1.7 keV is up to 2%, resulting in a transmission uncertainty within 1% for measured samples like ours. Above 1.7 keV, the stray light contamination is higher, and results in a measurement uncertainty up to 3%. Second order contamination is particularly significant at low energies ($E < 130$ eV), and in a small region above the carbon edge (290-300 eV), resulting in a measurement uncertainty of up to 30%. Outside of these regions, the measurement uncertainties are always lower than 3%.

1.2 Modeling the X-ray Transmission

The transmission model is a synthesis of the SAO and BESSY models as derived from the measurements. For energies at and below 1950 eV, the x-ray transmission is represented by the model derived from the BESSY data. Above 1950 eV, the transmission curve is based upon the mass areal densities derived from the SAO monochromator measurements. We are justified in taking this approach because the BESSY and SAO fits are statistically similar outside of the fine structure regions. Figure 3 shows this to be the case. It is a plot of the SAO and BESSY x-ray transmission models for the HRC-I UV/Ion shield. Superimposed on the models are the x-ray transmission measurement results obtained of the associated witness sample using the SAO x-ray monochromator. The SAO and BESSY derived models match up very well at 1950 eV.

Modeling of the synchrotron data was a two step process. We first applied a nonlinear fitting routine (the

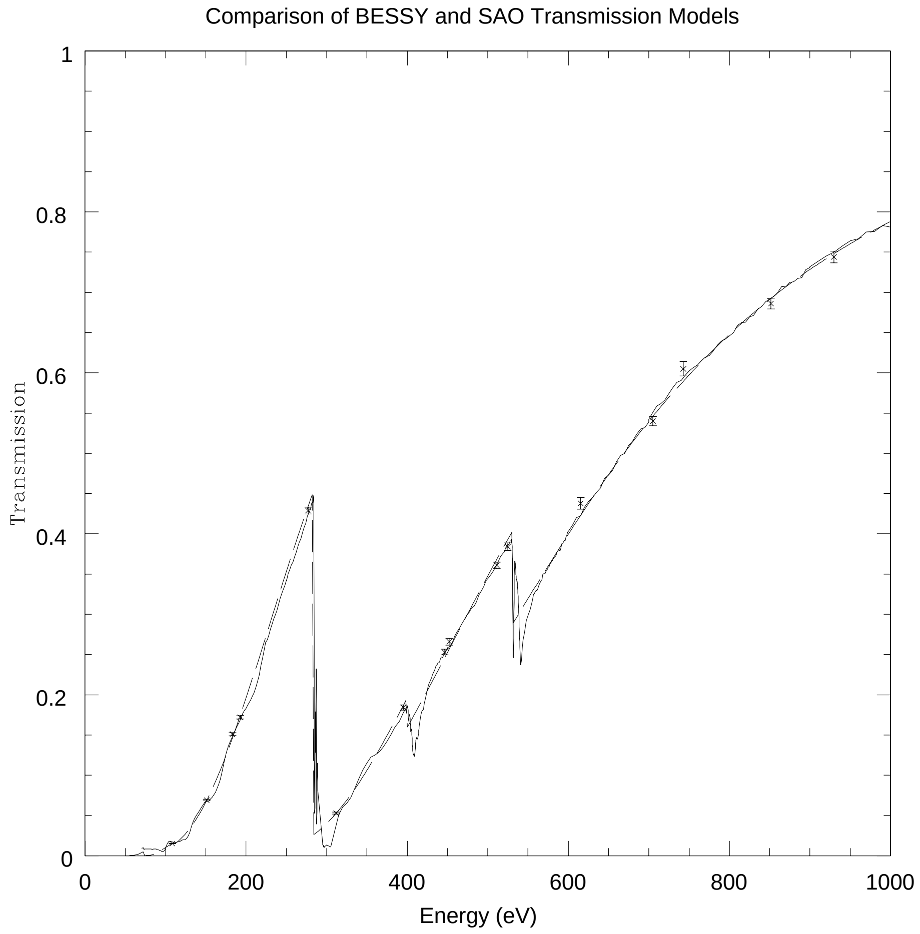

Figure 3: This plot demonstrates that, outside of the fine structure regions, we obtained statistically similar fits to transmission data of witness samples measured at both SAO (dashed line) and the BESSY facility (solid line). Superimposed on the model plots are the SAO x-ray transmission measurement points of the witness sample representing the HRC-I UV/Ion shield.

Levenberg-Marquardt algorithm) to the witness sample data set, to the exclusion of the absorption edge fine structure regions. The transmission of x-rays through N layers of material is represented by

$$T(E) = \prod_{i=1}^{N} e^{-(\frac{\mu(E)}{\rho})_i (\rho t)_i} \tag{1}$$

where the product of the material density and thickness, ρ and t, respectively, is called the mass areal density. In fitting a model to the data, the mass areal densities of Al, C, N and O were adjusted in such a way as to minimize the reduced χ^2 value of the fit. This same technique was applied to the SAO monochromator data sets.

From the derived mass areal densities, and the canonical densities of aluminum ($2.50\ g \cdot cm^{-3}$) and polyimide ($1.40\ g \cdot cm^{-3}$), one can determine the thickness of the constituent layers of the filter. Therefore, the x-ray transmission model for the UVIS-I can also be expressed as

$$T(E) = e^{-(\frac{\mu(E)}{\rho})_{Al}\rho_{Al}t_{Al}} e^{-(\frac{\mu(E)}{\rho})_{polym}\rho_{polym}t_{polym}} \tag{2}$$

The mass absorption coefficients are taken from Henke, *et al*, (1982). These coefficients provide the best statistical fit to our data.

The mass attenuation coefficients derived for a compound by taking into account only the individual atomic coefficients does not take into consideration fine structure features that occur near the absorption edges due to interactions of the photoelectrons with the closer atoms in the molecules of the compound (XANES and EXAFS). In order to define the mass attenuation coefficients of a compound that include these features, direct transmission measurements need to be conducted on the compound material of interest. Following the same technique described by us in an earlier work[3], we used the synchrotron measurements and the best fit model parameters of the witness sample with the thickest layer of polyimide (a flight witness sample for the HRC-I UV/Ion shield) to derive the mass attenuation coefficients of C, N, and O near their K absorption edges. Analogously, we used the measurements and the best fit model parameters of the witness sample with the thickest layer of aluminum (a flight witness sample for the HRC-S UV/Ion shield's -1 segment in the thick aluminum region) to derive the mass attenuation coefficients of Al near its K and L absorption edges.

1.3 UVIS-I Modeling Results

Table 3 presents the results of fitting the HRC-I UV/Ion shield x-ray transmission measurements with the SAO x-ray monochromator. Based on our measurements, we have derived an aluminum thickness of $759.6 \pm 20.4\AA$ and a polyimide thickness of $5490 \pm 158\AA$ for the flight UVIS-I. Luxel's aluminum and polyimide thickness measurements are $795 \pm 50\AA$ and $5300 \pm 100\AA$, respectively. Luxel's measurements agree with ours within the statistical uncertainties.

The overall x-ray transmission model for the flight UVIS-I is shown in figure 4. A more detailed plot in the 0 to 2 keV energy region is presented in figure 5. Figure 6 is similar to the previous one, except that it includes the measurement points obtained with the SAO x-ray monochromator. Figure 7 shows the UVIS-I x-ray transmission model in the 0 to 2 keV energy range, along with the BESSY measurements.

Figures 8 through 11 are detailed plots of the fine structure in the C, N, O and Al K-edge regions. Compared to the HRC-S UVIS results, these plots reveal that there is less agreement between the models and the data in three of the fine structure regions. For carbon, the deviation is in excess of several σ at some points. There are also some disagreements between the data and the model in the nitrogen and oxygen fine structure regions (on the order of 1σ). In the aluminum K-edge fine structure region, however, there is good agreement between the data and the fit. The discrepancy between the data and the model in the carbon fine structure region is most likely related to higher order contamination, which may be introducing errors in the derived mass absorption coefficients. This may account for the results obtained in the nitrogen and oxygen fine structure regions.

2 References

1. G.R. Meehan, S.S. Murray, M.V. Zombeck, R.P. Kraft, K. Kobayashi, J.H. Chappell, A.T. Kenter, M. Barbera, A. Collura, S. Serio, "Calibration of the UV/Ion Shields for the AXAF High Resolution Camera," Proc. SPIE, 3114, 1997

2. G.R. Meehan, A.T. Kenter, R.P. Kraft, S.S. Murray, M.V. Zombeck, K. Kobayashi, J.H. Chappell, M. Barbera, and A. Collura, "Measurement of the transmission of the UV/Ion Shields for the AXAF High Resolution Camera," Proc. SPIE, 2808, 1996.

3. Barbera, M., Collura, A., Dara, A., "Calibration of the AXAF-HRC UV/Ion shields at Osservatorio Astronomico di Palermo G.S. Vaiana: III - Synchrotron measurements of XANES in aluminum coated Lexan film samples," 1996, SPIE vol. 2808, 120.

2.1 Tables and Figures

Flight Filter Segment	Composition and Luxel Thickness Measurements	Test Method
HRC-I	Aluminum $795 \pm 50\AA$ Polyimide $5300 \pm 100\AA$	Synchrotron SAO Monochromator

Table 1: Description of the witness samples that were tested with the SAO x-ray monochromator, and at the BESSY Synchrotron Light Source Facility.

Beam Filter	Energy range (eV)	energy step (eV)	Absorption Edge
Beryllium 0.25 μm	60 – 71	1	
Beryllium 0.25 μm	71.2 – 75	0.2	Aluminum LII,LIII
Beryllium 0.25 μm	76 – 110	1	
No Filter	100 – 250	2	
Titanium 1 μm	250 – 280	2	
Titanium 1 μm	280.5 – 293	0.5	Carbon K
Titanium 1 μm	295 – 400	5	
Titanium 1 μm	400.2 – 415	0.2	Nitrogen K
Titanium 1 μm	416 – 450	1	
Iron 0.5 μm	450 – 520	3	
Iron 0.5 μm	521 – 529	1	
Iron 0.5 μm	529.2 – 540	0.2	Oxygen K
Iron 0.5 μm	541 – 565	1	
Iron 0.5 μm	541 – 600	1	
Iron 0.5 μm	605 – 700	5	
Copper 0.5 μm	700 – 900	5	
Berylium 7 μm	900 – 1540	10	
Berylium 7 μm	1542 – 1600	2	Aluminum K
Berylium 7 μm	1605 – 1700	5	
Berylium 7 μm	1710 – 1950	10	

Table 2: Energies surveyed in the BESSY synchrotron transmission measurements.

Al (μg/cm^2)	C (μg/cm^2)	N (μg/cm^2)	O (μg/cm^2)	Reduced χ^2
18.99 ± 0.51	54.01 ± 1.13	6.80 ± 1.21	16.02 ± 1.47	2.448

Table 3: Computed mass areal densities based on 1982 Henke coefficients for the HRC-I UV/Ion shield witness sample measured with the SAO x-ray monochromator. The reduced χ^2 value is included.

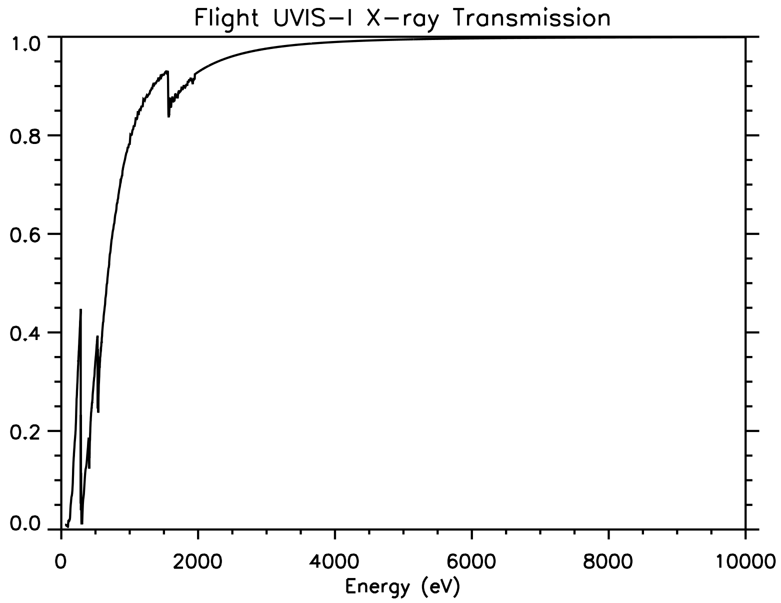

Figure 4: The flight UVIS-I x-ray transmission model. It is the result of combining the BESSY synchrotron data with the SAO monochromator model.

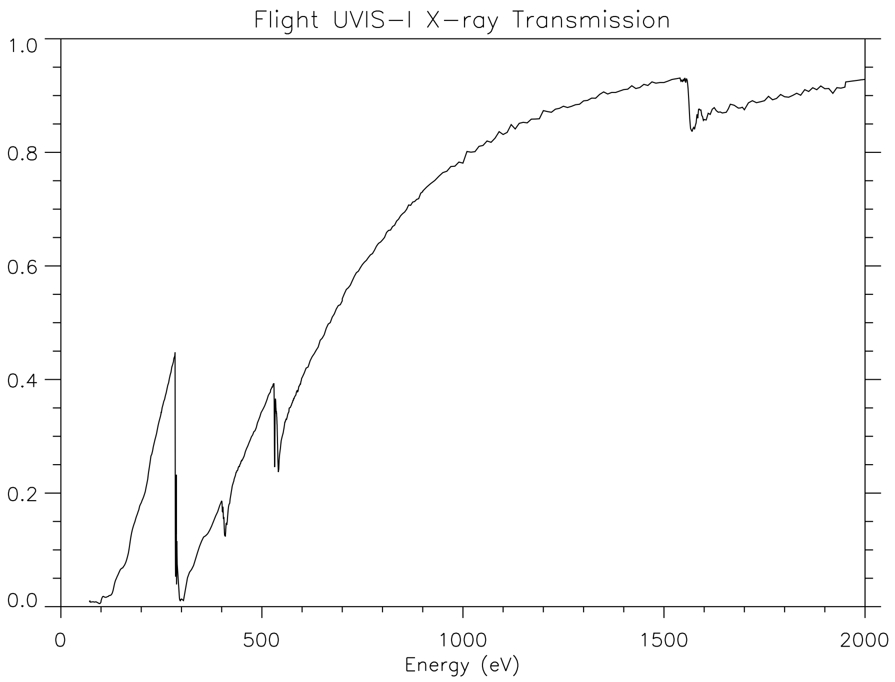

Figure 5: This is a plot of the above model, but displayed over the 0 to 2,000 eV energy range.

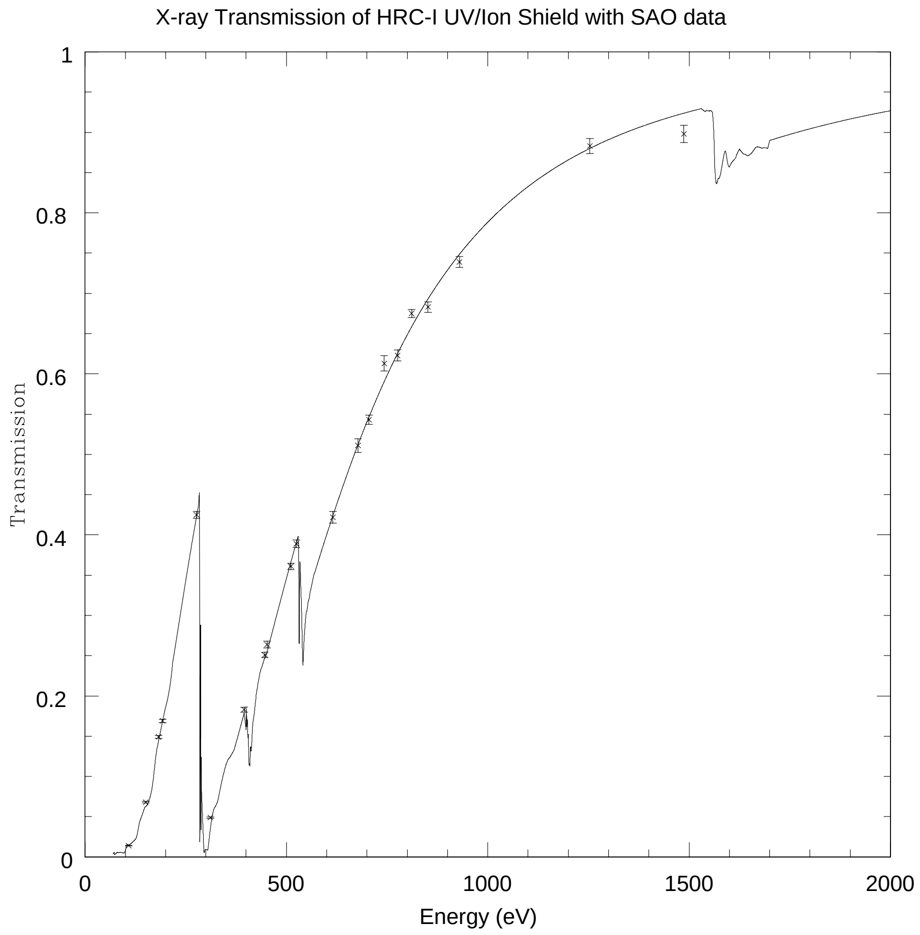

Figure 6: This is a plot of the x-ray transmission model of the UVIS-I displayed over the 0 to 2,000 eV energy range. Superimposed over this model are the measurement points obtained with the SAO x-ray monochromator.

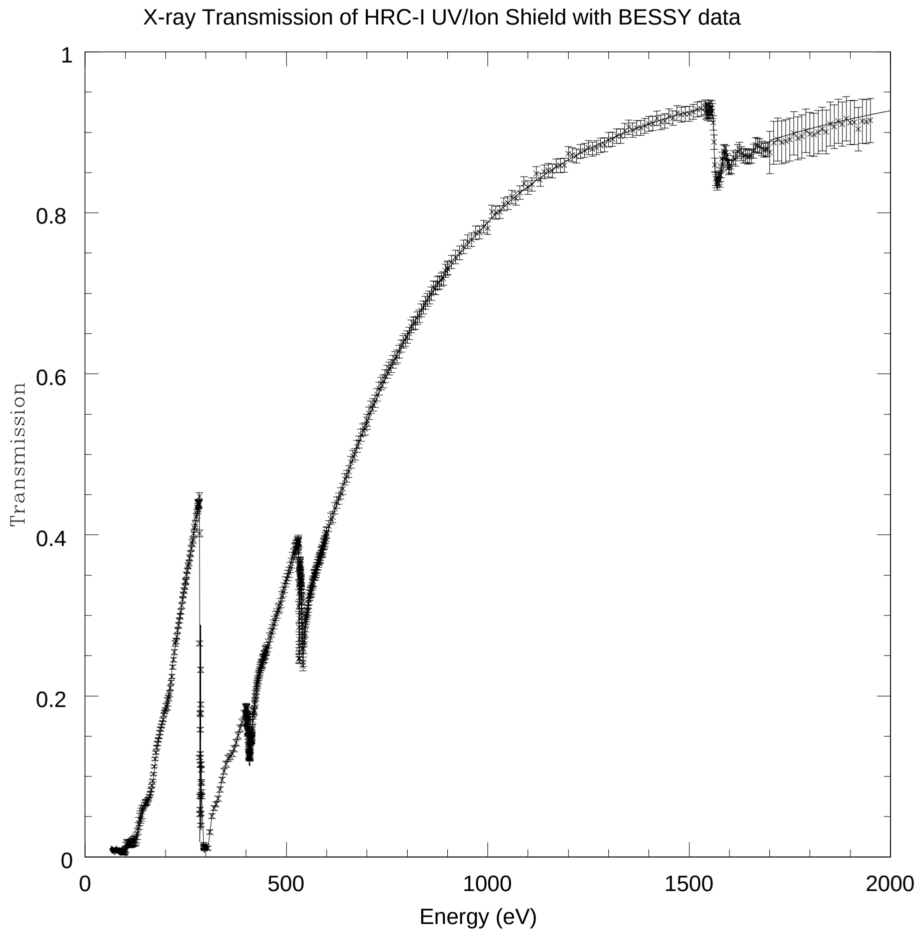

Figure 7: This is a plot of the x-ray transmission model of the UVIS-I displayed over the 0 to 2,000 eV energy range. Superimposed over this model are the measurement points obtained with the BESSY synchrotron.

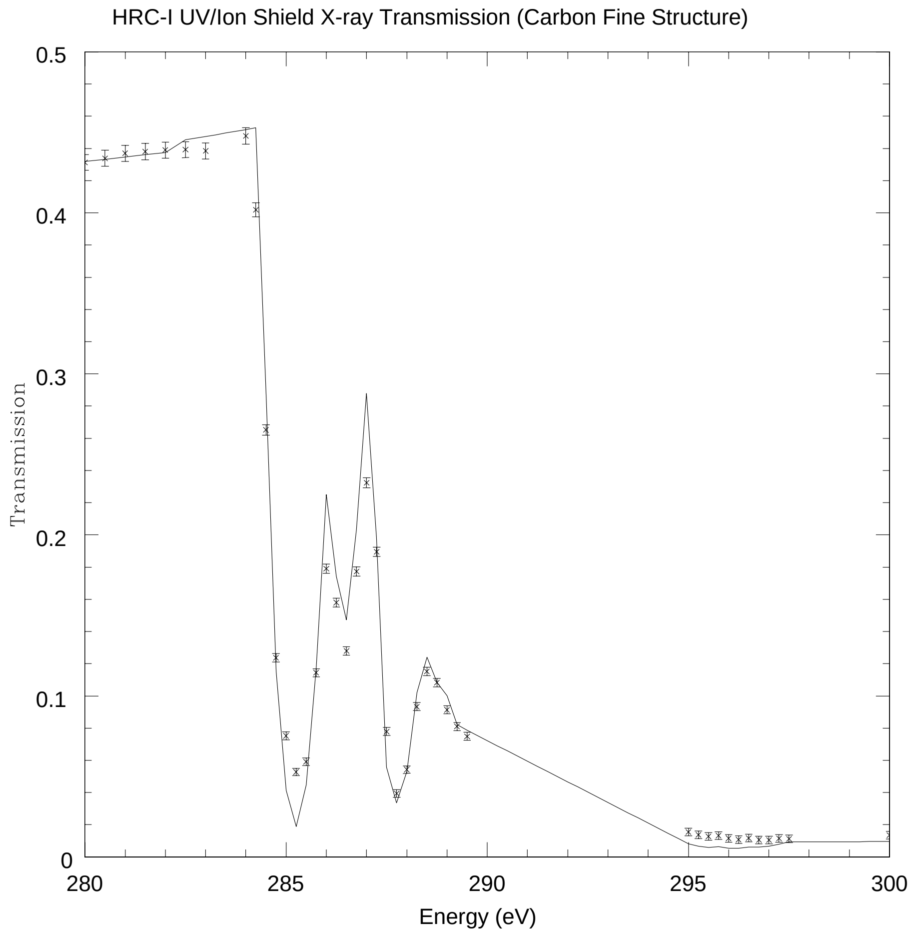

Figure 8: The flight UVIS-I x-ray transmission model in the carbon K-edge fine structure region. The model in this region is represented by the x-ray transmission data obtained with the BESSY synchrotron.

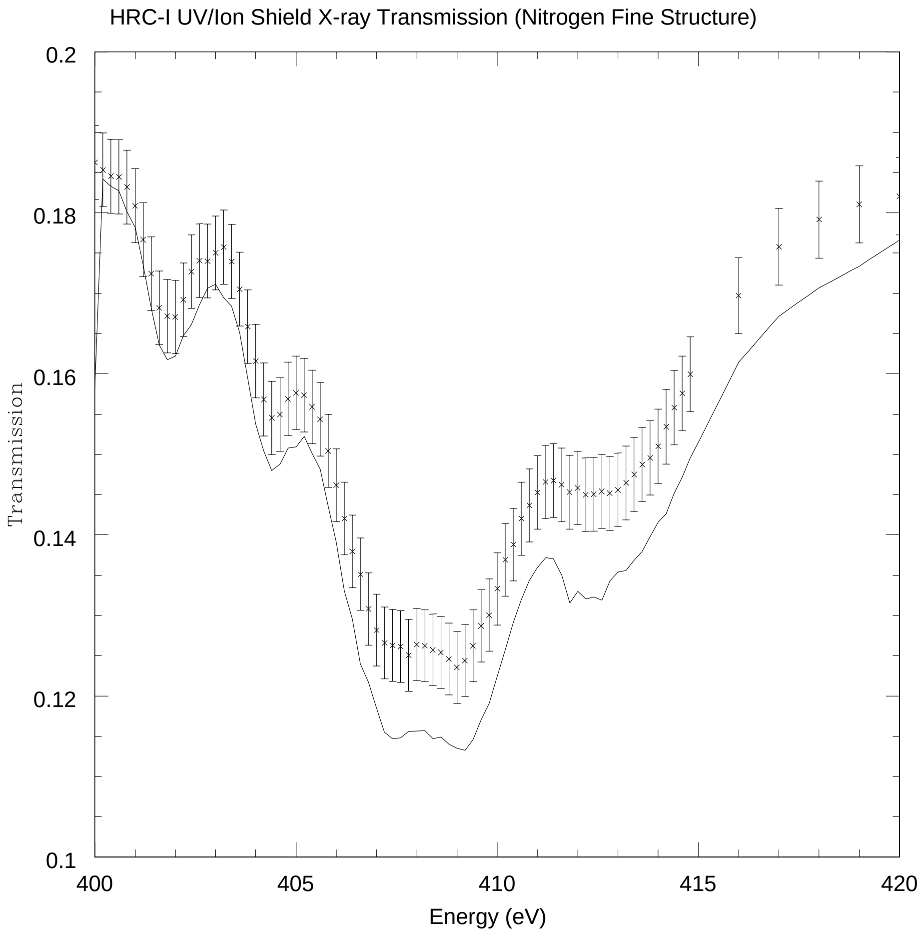

Figure 9: The flight UVIS-I x-ray transmission model in the nitrogen K-edge fine structure region. The model in this region is represented by the x-ray transmission data obtained with the BESSY synchrotron.

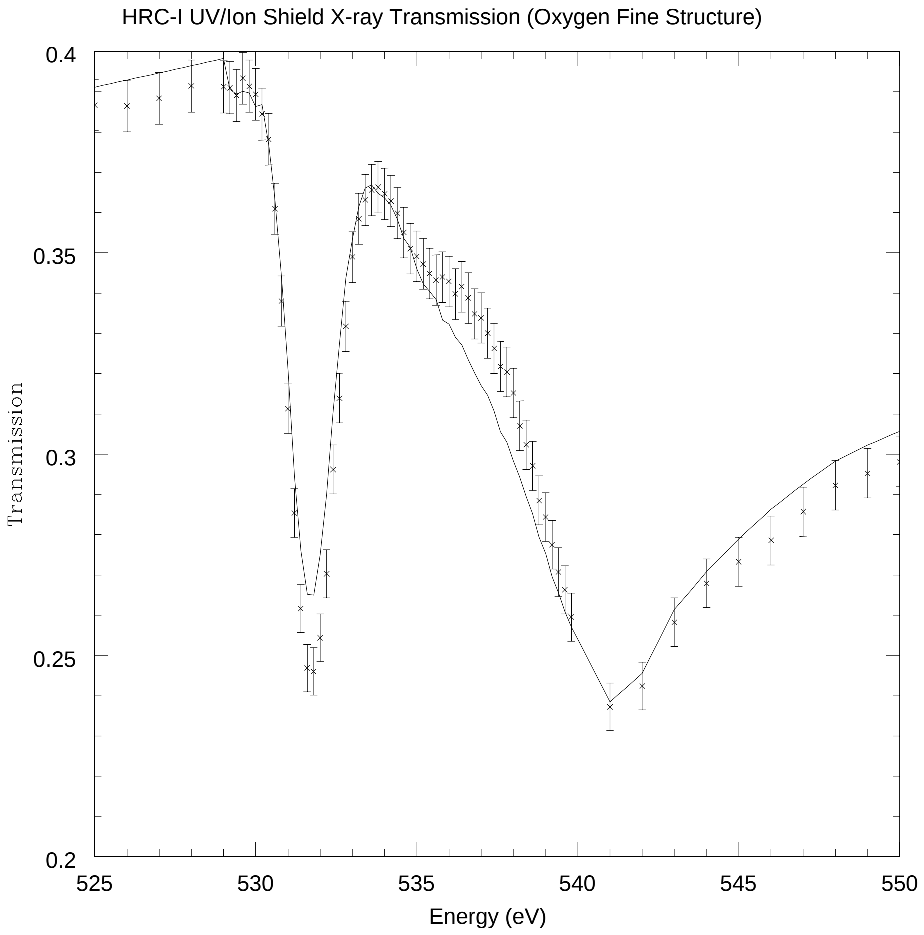

Figure 10: The flight UVIS-I x-ray transmission model in the oxygen K-edge fine structure region. The model in this region is represented by the x-ray transmission data obtained with the BESSY synchrotron.

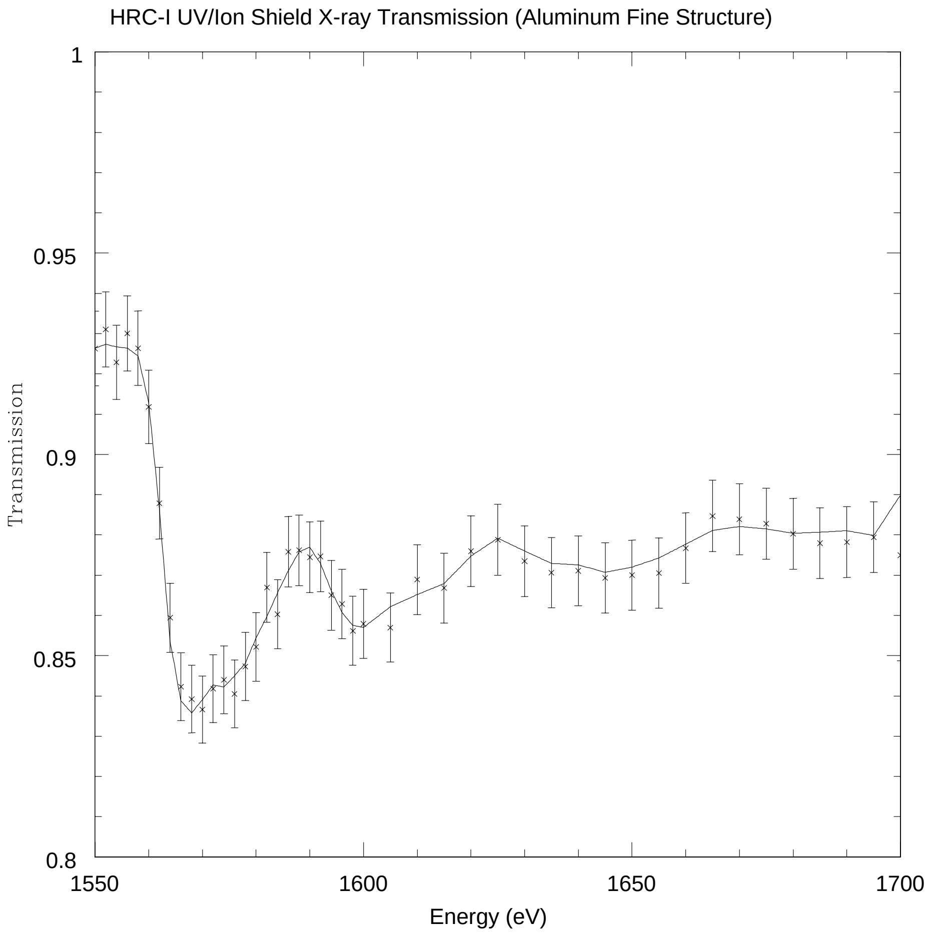

Figure 11: The flight UVIS-I x-ray transmission model in the aluminum K-edge fine structure region. The model in this region is represented by the x-ray transmission data obtained with the BESSY synchrotron.