Redetermination of Sensitivity for Echelle-A and G140M

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ABSTRACT

This ISR describes a redetermination of the GHRS sensitivity functions for the Echelle-A and G140M gratings. Changes amount to ~20% for Echelle-A over the entire range of wavelengths, compared to the previous values. G140M also deviates slightly from the reference spectrum and requires a linear correction with wavelength, amounting to ~2% at 1100 Å and 8% at 1600 Å. The procedures used to derive the corrected sensitivity functions are described here, and new files have been installed in the CDBS.

1. Introduction

Calibrating GHRS spectra involves translating the observed pixel position to wavelength and the observed counts to units of flux. Wavelength determination is relatively straightforward, relying on observations of the wavelength calibration lamp within the instrument. Flux calibration, on the other hand, is based on observations of standard stars which contain a number of absorption features and a detector whose response can vary with wavelength, spatial position, and time. These factors must be taken into careful consideration when determining the sensitivity function for a given grating.

When comparing the pipeline-calibrated flux spectrum for the standard star μ Col, taken with Echelle-A, with its expected reference flux, a significant deviation was apparent, indicating that the sensitivity function that was made available in SMOV was incorrect. Discrepancies for G140M were also evident. Flux ratios for G140M were not as poorly matched as in the case of Echelle-A, yet there was an apparent deviation which varied linearly with wavelength, affecting the spectrum significantly from about 1250 to 1600 Å. The extent of these corrections and the sensitivity redetermination for these two gratings is outlined in sections 3 and 4.

2. Sensitivity Determination and Limitations

"Sensitivity" is the function used to convert detected count rates to absolute flux values. It is defined as the flux per count rate, $S_\lambda = F_\lambda / C_\lambda$, in units of (erg cm^{-2} s^{-1} Å^{-1}) per (counts s^{-1} diode^{-1}). Sensitivity determination involves first the observation of a standard star over the full useful range of the grating, giving a standard spectrum, in units of count rate, as a function of wavelength. This spectrum is to be ratioed with the reference spectrum for the standard star, the true representation of flux at each wavelength. Figure 1 shows the observed spectrum, C_λ, of the standard star μ Col, plotted with its reference spectrum, F_λ, taken with the IUE, found in the CDBS CALOBS directory.

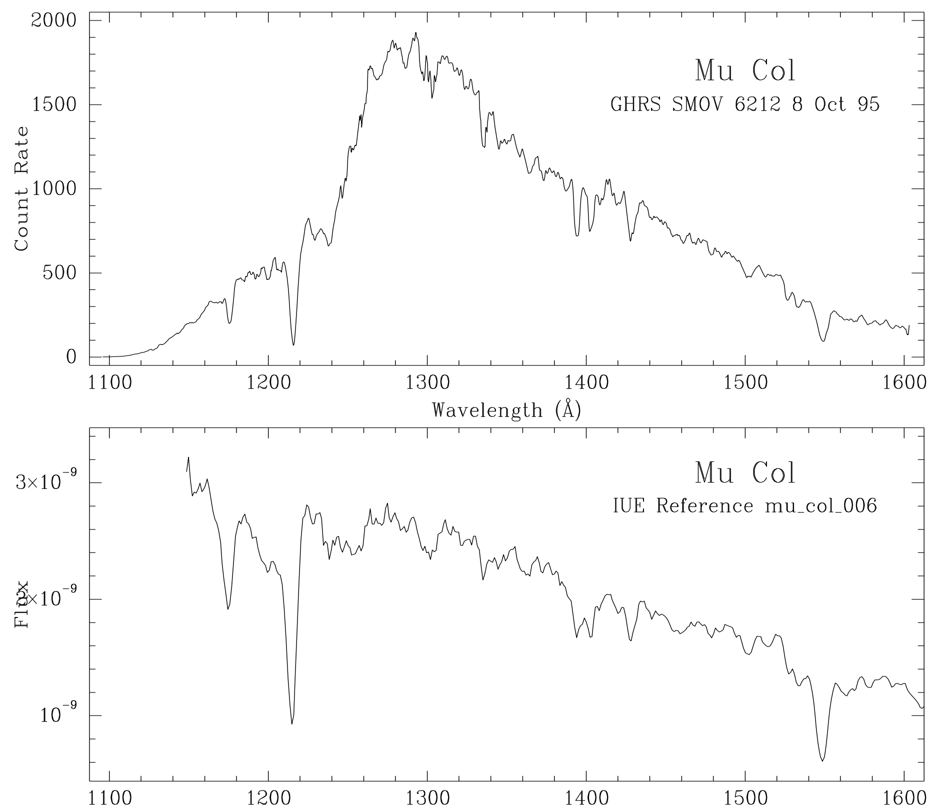

Figure 1: Observed spectra C_λ of standard star μ Col with GHRS G140M compared to its reference spectrum F_λ taken with the IUE.

A number of complications must be considered in determining the sensitivity, specifically that we have neither a perfect star nor a perfect detector to work with. Real stars, particularly those used as standards for UV flux calibration, have many spectral features making it difficult to divide one spectrum by another. It becomes difficult to determine the calibration in the region of Lyman-α because it is such a broad feature. Also, Lyman-α lies on a portion of the observed spectrum with a steep slope where the grating sensitivity is declining rapidly. As a result, the intrinsic uncertainty in fluxes in the region of Lyman-α is higher than at other wavelengths. In addition, the detector does not necessarily have a response function that is perfectly flat across its face, but may vary with wavelength, spatial position, and time. To further complicate the process, the amount of light seen through the Small Science Aperture (SSA) of the GHRS is very sensitive to how well the object was centered in the aperture. These factors will be addressed in the discussion below.

3. The Calibration of Echelle-A

Preliminary analysis of Echelle-A began with the Cycle 4 observations of μ Col from the GHRS Ech-A Sensitivity Calibration on March 25, 1994. Table 1 lists the files used with their corresponding aperture, exposure time, grating order, and central wavelength. These files were calibrated through the pipeline using the most recent reference files and the STSDAS task `hst_calib.calhrs`. Header switches were set as described in GHRS-ISR-085 for the calibration of G140M and are given in Table 2.

Table 1: Cycle 4 Echelle-A Observations of μ Col

ROOTNAME (LSA)	ROOTNAME (SSA)	EXPTIME	DATE-OBS	Order	Central Wavelength
Z2AF011AT	Z2AF021ET	108.8	03/25/94	49	1144.8
Z2AF0119T	Z2AF021DT	108.8	03/25/94	48	1168.7
Z2AF0118T	Z2AF021CT	108.8	03/25/94	47	1193.5
Z2AF0117T	Z2AF021BT	108.8	03/25/94	46	1219.5
Z2AF0115T	Z2AF02109T	27.2	03/25/94	45	1246.6
Z2AF0114T	Z2AF0218T	27.2	03/25/94	44	1275.0
Z2AF0113T	Z2AF0217T	27.2	03/25/94	43	1304.6
Z2AF0112T	Z2AF0216T	27.2	03/25/94	42	1335.6
Z2AF0111T	Z2AF0215T	27.2	03/25/94	41	1368.2
Z2AF0110T	Z2AF0214T	27.2	03/25/94	40	1402.4
Z2AF010ZT	Z2AF0213T	27.2	03/25/94	39	1438.4
Z2AF010YT	Z2AF0212T	27.2	03/25/94	38	1476.2
Z2AF010WT	Z2AF0210T	108.8	03/25/94	37	1516.1
Z2AF010VT	Z2AF020ZT	108.8	03/25/94	36	1558.2
Z2AF010UT	Z2AF020YT	108.8	03/25/94	35	1602.7
Z2AF010TT	Z2AF020XT	108.8	03/25/94	34	1649.9
Z2AF010ST	Z2AF020WT	108.8	03/25/94	33	1699.9

Table 2: Calibration Switch Settings

SWITCH	SETTING	SWITCH	SETTING	SWITCH	SETTING
DQI_CORR	PERFORM	VIG_CORR	PERFORM	BCK_CORR	OMIT
EXP_CORR	PERFORM	MER_CORR	PERFORM	IAC_CORR	PERFORM
DIO_CORR	PERFORM	ADC_CORR	PERFORM	ECH_CORR	PERFORM
PPC_CORR	PERFORM	MDF_CORR	OMIT	FLX_CORR	PERFORM
MAP_CORR	PERFORM	MNF_CORR	OMIT	HEL_CORR	PERFORM
DOP_CORR	OMIT	BMD_CORR	OMIT	VAC_CORR	OMIT
PHC_CORR	PERFORM	PLY_CORR	PERFORM	GWC_CORR	PERFORM

In determining whether the recommended sensitivity file (e5v0936nz.r3h) is adequate, we must compare the flux calculated using this sensitivity with the reference spectrum for the same star. The Echelle-A files, however, cover only a narrow bandpass per exposure (~6 Å at 1100 Å) and are separated by wavelengths on the order of 30 Å for the Cycle 4 observations. For this reason, it was not possible to overplot the spectra and take a simple ratio since the observations are not continuous over the entire range of wavelengths. It was thus useful to determine the average flux at the center of the band for each file and overplot onto the reference file. These results (Figure 2a) show that the flux for Echelle-A is significantly greater than what we expect, increased by about 19% over the entire range of wavelengths for both the LSA and the SSA observations. This result was confirmed by examining the data from the GHRS Cycle 5 Long-Term Monitor (Feb. 6, 1996) and the Cycle 6 Long-Term Monitor (Dec. 28, 1996) for which offsets of 15% and 19% were derived for the LSA. Because aperture miscentering can lead to decreased flux values, and thus a smaller discrepancy between the measured and reference flux values, we adopt the larger number for making our correction.

The absolute flux correction (FLX_CORR) converts counts to absolute flux units by dividing by the sensitivity. In order to bring the measured flux and reference flux into agreement, we must thus increase the sensitivity function by 19%. Data were recalibrated incorporating this change, resulting in good agreement for both the LSA and SSA (Figure 2b). The degree of change in the previous sensitivity functions is illustrated in Figure 3 by plotting the original LSA and SSA curves with the newly determined curves.

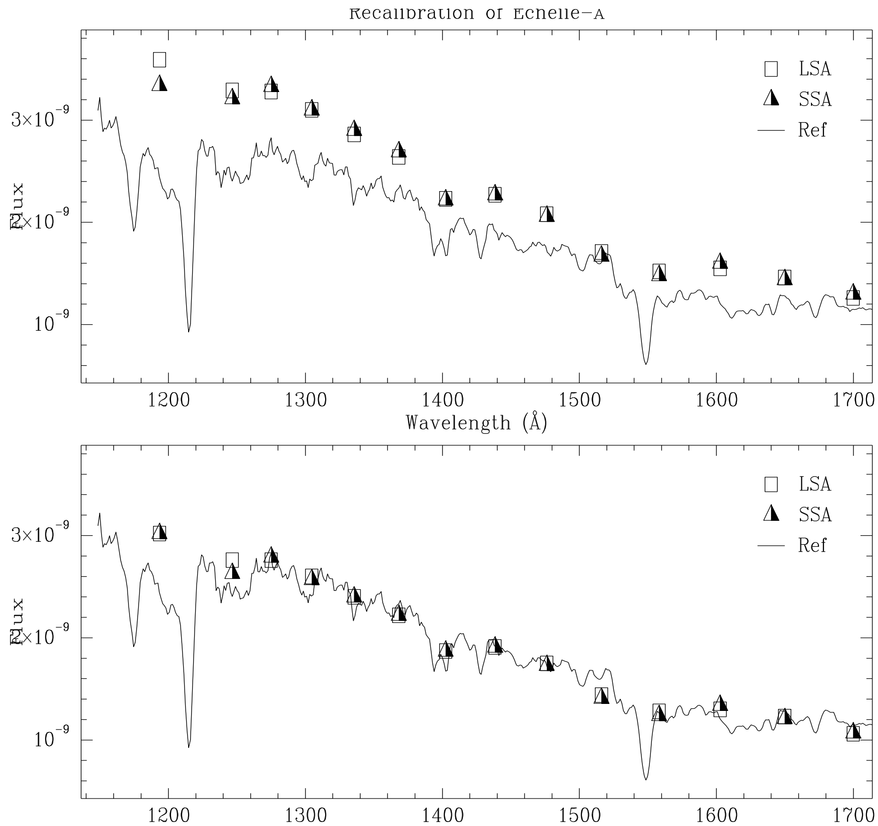

Figure 2: The reference flux for μ Col is plotted with the calculated values from Echelle-A. *a)* Both LSA and SSA show an excess flux of ~19% using the old sensitivity file. *b)* Measured and reference flux values agree once a constant factor is applied.

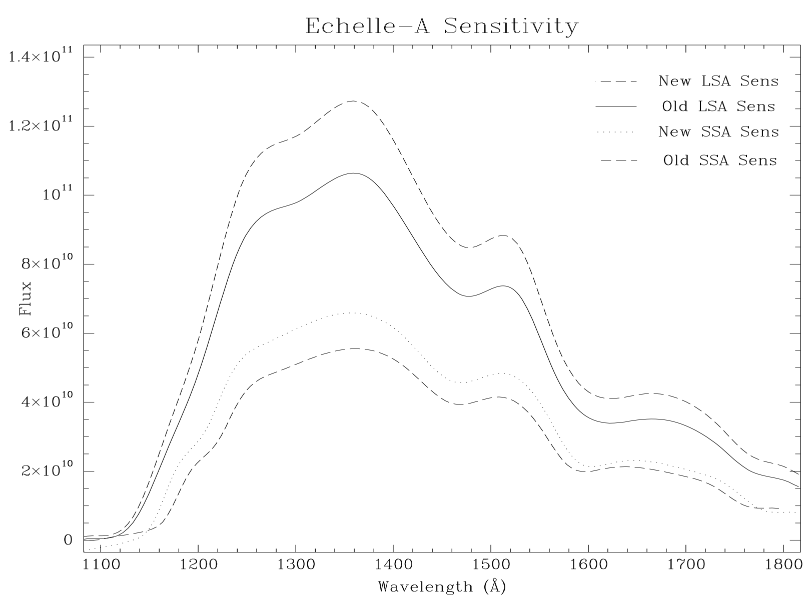

Figure 3: The sensitivity function (e5v0936nz.r3h) for the LSA and the SSA is plotted with the new sensitivity file with the appropriate corrections.

4. The Calibration of G140M

LSA Sensitivity

A similar approach was taken for verifying the G140M sensitivity. Data from the GHRS G140M Sensitivity and Vignetting Calibration (Cycle 5: October 8, 1995) were recalibrated with the recommended reference files and the calibration switches given above, except with ECH_CORR set to OMIT.

Table 3: G140M Observations of μ Col

ROOTNAME (LSA)	ROOTNAME (SSA)	EXPTIME	DATE-OBS	Carrousel Position	Central Wavelength
Z2XE0108T	Z2XE0112T	81.6	10/8/95	18468	1110.0
Z2XE0109T	Z2XE0113T	81.6	10/8/95	18400	1130.2
Z2XE010AT	Z2XE0114T	81.6	10/8/95	18332	1150.4
Z2XE010BT	Z2XE0115T	81.6	10/8/95	18264	1170.5
Z2XE010CT	Z2XE0116T	81.6	10/8/95	18196	1190.6
Z2XE010DT	Z2XE0117T	27.2	10/8/95	18128	1210.7
Z2XE010ET	Z2XE0118T	27.2	10/8/95	18060	1230.7
Z2XE010FT	Z2XE0119T	27.2	10/8/95	17992	1250.6
Z2XE010GT	Z2XE011AT	27.2	10/8/95	17924	1270.5
Z2XE010HT	Z2XE011BT	27.2	10/8/95	17856	1290.4
Z2XE010IT	Z2XE011CT	27.2	10/8/95	17788	1310.2
Z2XE010JT	Z2XE011DT	27.2	10/8/95	17720	1329.9
Z2XE010KT	Z2XE011ET	27.2	10/8/95	17648	1350.7
Z2XE010LT	Z2XE011FT	27.2	10/8/95	17580	1370.3
Z2XE010MT	Z2XE011GT	27.2	10/8/95	17512	1389.9
Z2XE010NT	Z2XE011HT	54.4	10/8/95	17440	1410.5
Z2XE010OT	Z2XE011IT	54.4	10/8/95	17372	1429.9
Z2XE010PT	Z2XE011JT	54.4	10/8/95	17300	1450.5
Z2XE010QT	Z2XE011KT	54.4	10/8/95	17232	1469.8
Z2XE010RT	Z2XE011LT	54.4	10/8/95	17160	1490.1
Z2XE010ST	Z2XE011MT	54.4	10/8/95	17088	1510.4
Z2XE010TT	Z2XE011NT	54.4	10/8/95	17016	1530.7
Z2XE010UT	Z2XE011OT	54.4	10/8/95	16948	1549.7
Z2XE010VT	Z2XE011PT	54.4	10/8/95	16876	1569.8
Z2XE010WT	Z2XE011QT	54.4	10/8/95	16804	1589.8

This dataset spans a range of 1100-1600 Å, with each observation covering a bandpass of ~28 Å and overlapping the adjacent file by ~8 Å. The next step is therefore merging the data from the different carrousel positions into one spectrum with the STSDAS task `z_calib.mergecar`. Using this task, the GHRS data are binned into linear 1 Å wavelength bins, and overlapping regions are averaged together. The binned, merged data is then smoothed to the resolution of the reference spectrum and plotted for comparison in Figure 4a. The resulting spectrum is divided by the reference spectrum using the STSDAS task `z_calib.abssenz` (matching wavelength bins). The ratio should be equal to one and should be flat for the entire range of wavelengths, assuming the applied sensitivity function (e5v0936qz.r3h) is accurate.

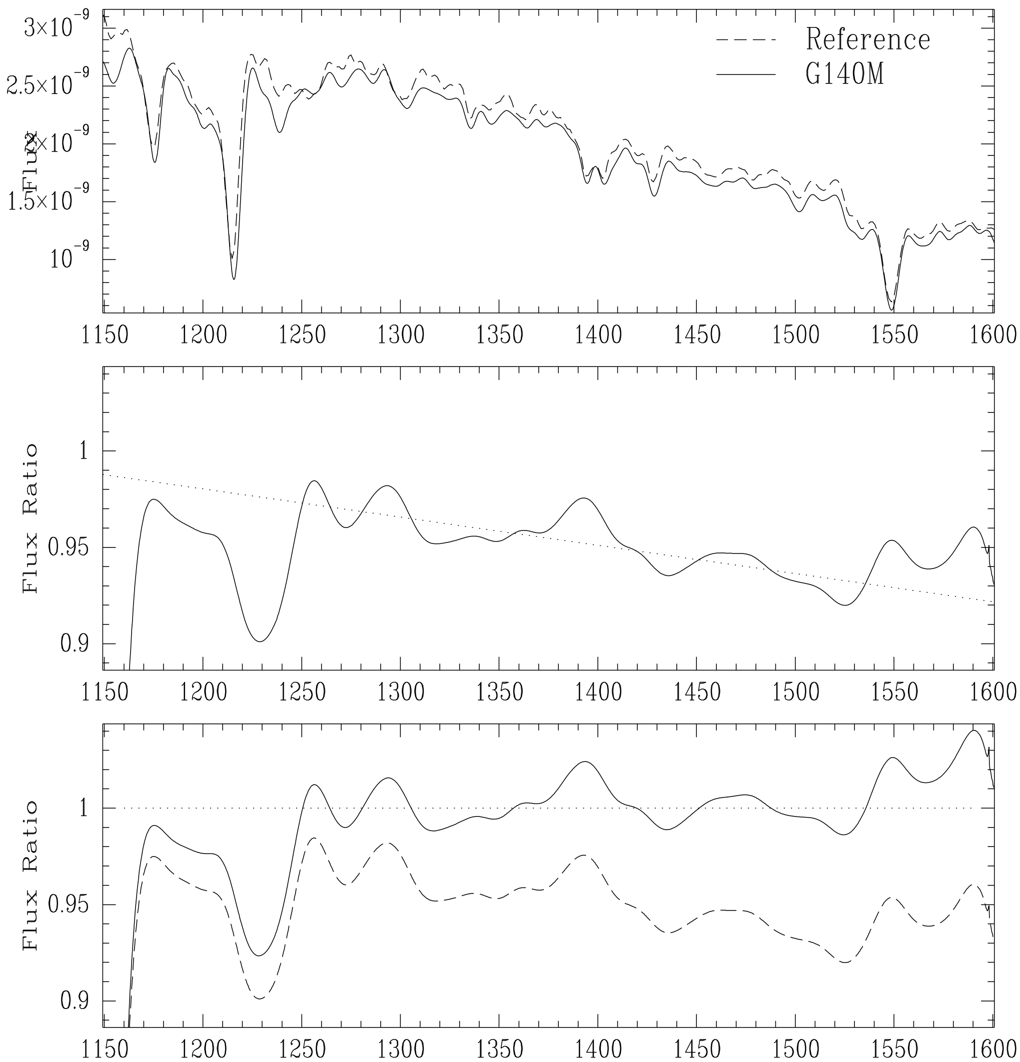

Figure 4: *a)* The reference IUE spectrum for μ Col is plotted with the merged G140M data using the most current reference files. *b)* The ratio of G140M to the reference spectrum is fit with a linear function for use in correcting the sensitivity. *c)* Applying the linear correction to the current sensitivity function improves the ratio dramatically.

Examination of ratio in Figure 4b indicates that the calculated (observed) flux is too low, implying that the sensitivity values are too large by about 5%. This offset, however, is not constant over the entire range of wavelengths but appears to increase linearly with wavelength requiring only a ~1% correction at 1100 Å and an 8% correction at 1600 Å. The STSDAS fitting task `gfit` was used to fit a cubic spline to the ratio from 1250 to 1500 Å in order to define precisely the offset. This range was chosen because it is free from large absorption features in the spectrum. The resulting linear equation was multiplied by the original sensitivity file, the data recalibrated, and the spectra ratioed again. This ratio is shown in Figure 4c and confirms that our new sensitivity file is correct. The feature at 1230 Å is due to difficulty in matching both the spectral resolution in Ångstroms (achieved by smoothing the data) and the width of the Lyman-α absorption feature. The corresponding dip the ratio is an artifact of the division process and should not be interpreted as a flaw in the sensitivity.

SSA Sensitivity

Determining the sensitivity for the SSA is not as straightforward, since the amount of light detected depends on how well the object is centered in the aperture. It is therefore useful to examine the SSA/LSA ratio and then multiply the baseline LSA sensitivity curve by this ratio to determine the SSA sensitivity. Data were calibrated using the standard reference files, but with no flux correction this time, so that the derived intensity is in units of counts and does not risk reflecting the signature of an inaccurate sensitivity profile. The merged data for each aperture were aligned and ratioed, yielding a value of ~0.3. To check this result, we divided the original SSA and LSA sensitivity curves (e5v0936zq.r3h) which gave ~0.55, a value closer to what we expected for this grating. In an attempt to shed light on these differing results, data from several other calibration proposals was examined in an effort to determine if miscentering of the object in the SSA could be the cause of the apparent discrepancy.

Using the files in units of count rate, the ratios were calculated in three ways: using the entire merged spectrum, using the central 10 Å, and using the central 20 Å of each file (a method which would eliminate potential vignetting effects). While the three different methods yield the same results (Figure 5), each epoch gives a different answer for the SSA/LSA ratio. We examined these observations and concluded that poor centering of the star was the cause of the low throughput in all cases but one. In that one case (May 2, 1995) the throughput is low but the centering appeared to be good, and we do not understand the results.

For simplicity, we adopt the ratio determined by dividing the old SSA and LSA sensitivity functions. This gives a value of 0.5 at 1100 Å and linearly increasing to 0.57 at 1600 Å. The resulting SSA sensitivity function is determined by multiplying the LSA function calculated above by this ratio. The previous sensitivity functions and the corrected functions derived here are plotted in Figure 6 for both the LSA and the SSA.

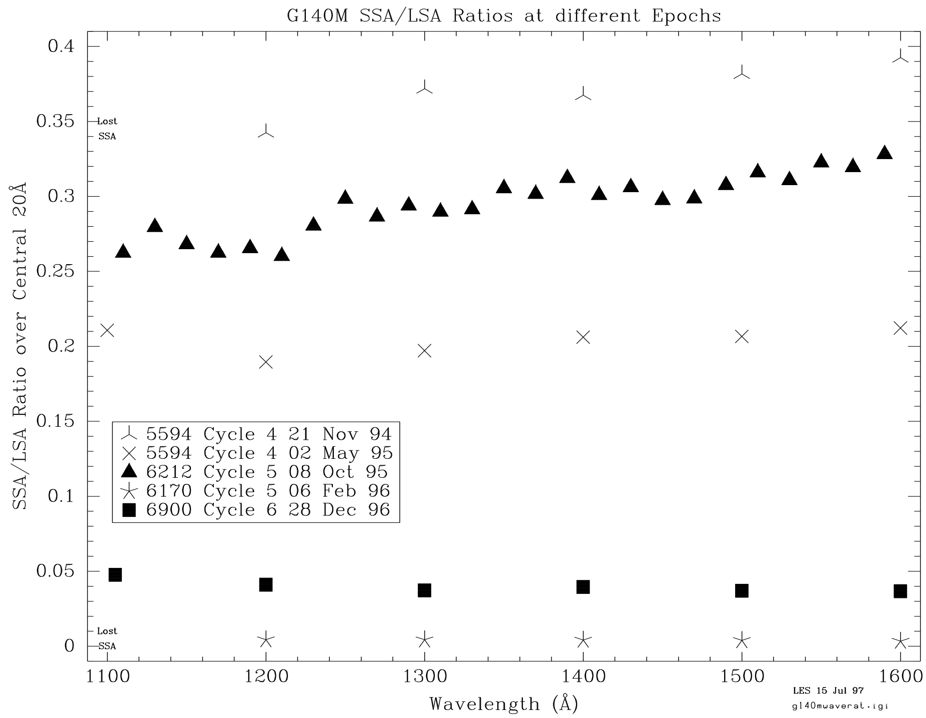

Figure 5: The SSA/LSA ratio is plotted for each of the G140M calibration proposals. The ratio is determined for each file, using no flux correction, and using the central 10 Å of each dataset.

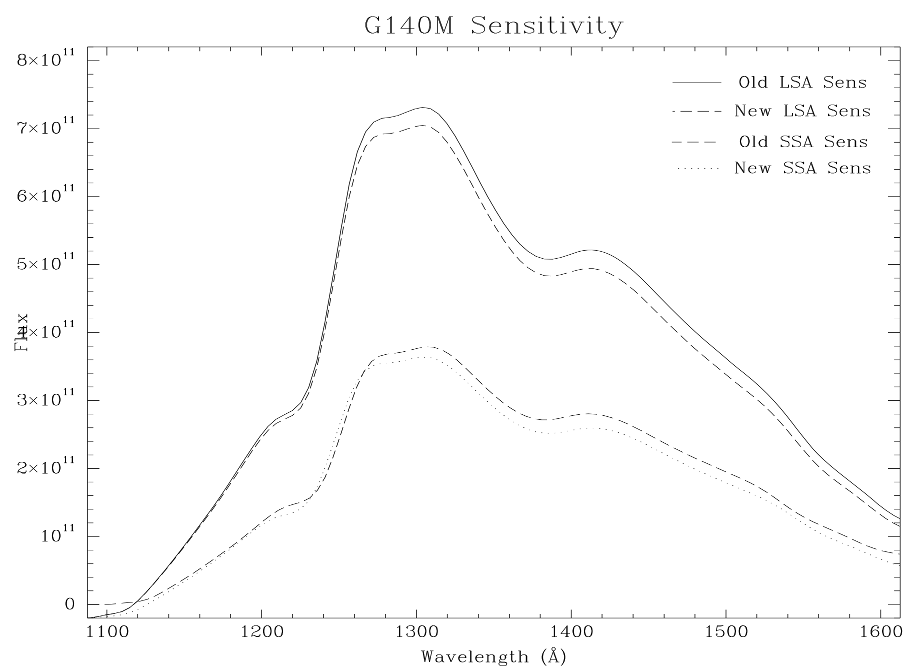

Figure 6: The previous sensitivity functions are plotted with the corrected curves, illustrating the extent of the change required to match the G140M data with the reference spectrum of μ Col.

5. Conclusion

We have redetermined the sensitivity files for GHRS grating Echelle-A and G140M. A simple constant offset of about 19% for both the LSA and the SSA is necessary to correct the Echelle-A data. G140M requires a linear correction with wavelength of about 5% for the LSA. This deviation is verified by examining data from several calibration proposals. The SSA sensitivity is derived by multiplying the corrected LSA sensitivity by the SSA/LSA ratio. Because this ratio can vary dramatically depending on centering of the target in the SSA, we adopt the ratio determined by dividing the old SSA and LSA sensitivity functions.