SV 1343 INTERIM REPORT

Grating Scatter in the FOS and the GHRS

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ABSTRACT

Grating scatter significantly affects FOS spectra of red objects below 2100Å wavelength. It also affects some GHRS spectra, but to a lesser extent. Below 1800Å, a GHRS G140L ("solar blind") spectrum of the G2V star 16 Cyg B, obtained in May, 1991, may be used to estimate what an ideal instrument, free of grating scatter, would measure. This spectrum may therefore be used to correct future FOS G190H spectra of solar-like objects, including planets. Between 1800Å and 2100Å, it is currently recommended to correct FOS spectra using pre-flight laboratory measurements, pending further analysis of grating scatter in GHRS G200M spectra.

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INTRODUCTION

The original goal of this SV test was to measure instrumentally scattered, long–wavelength light within the FOS, specifically for observations of red objects. This would be accomplished by comparing nearly simultaneous observations of a common target with both the FOS and the GHRS. One specific aim had been to see if the FOS G190H could reliably overlap with the GHRS G140L, which is effectively "solar–blind", to provide an efficient means of covering the spectral range from 1600 to 2300Å for red objects. However, with the loss of Side 1 of the GHRS, the usefulness of the FOS G190H for red objects below 2000Å has become a more critical question, and systematic ways to minimize the effects of grating scatter are needed. Furthermore, it has been realized during the data analysis that there is probably significant, though smaller, grating scatter within the GHRS G200M and G270M gratings.

DATA

On 27 May, 1991, the G2V star 16 Cyg B was observed by both the FOS and the GHRS. The observations are summarized in Table I below.

TABLE I.

		"Side"	Spectral Range or central wavelength	Exposure time
FOS	G190H	Blue	1570 - 2330Å	31.5M
	G270H	Blue	2230 - 3300Å	5.2M
	G160L	Blue	1150 - 2520Å	8.4M
GHRS	G140L	1	cent. wavelength 1700Å	68.6M
	G270M	2	24 settings, 2300 - 3220Å centers	95.2S - 29.4S
	G200M	2	12 settings, 1800 - 2185Å centers	26.6M - 4.2M (total = 172.2M)

ANALYSIS

Because the two spectrographs have different detectors, with different spectral ranges, it is possible to determine some characteristics of grating scatter by intercomparing them. For example, the G140L grating is on side 1 of the GHRS, which has a CsI photocathode. It is extremely insensitive to light at wavelengths longer than 1800Å, and is therefore "solar blind". That is, it is not susceptible to spurious detection of the vast excess of longer wavelength photons present in light from red objects such as the Sun. G200M and G270M are on side 2, with a CsTe photocathode that is sensitive up to 3200Å. G200M spectra of red objects below 2000Å are therefore somewhat susceptible to grating scatter.

The FOS "blue" side detector is sensitive up to visible wavelengths. It is therefore extremely susceptible to grating scatter. It may be noted that the FOS "red" detector, which is everywhere more sensitive than the blue one, is relatively more sensitive at longer wavelengths. It is therefore potentially more susceptible to grating scatter than the blue detector, for which reason it was not chosen at the time this test was planned.

16 Cyg B is both an HST ultraviolet standard and a solar analog (Hardorp, 1978). Because of its strong similarity to the Sun, it is possible to use solar spectra for an approximate, independent check on the HST observations of 16 Cyg B. Furthermore, pre–launch laboratory test data (Blair *et al.*, 1989) from the FOS are available to compare with the in–orbit results.

The GHRS data were first composited into a single spectrum covering the range 1600 – 3300Å. It was then necessary to harmonize the wavelength sampling of the two spectrographs. Each spectrum is originally oversampled, with multiple samples per Å. In each case, the data were resampled on .5Å centers. Each sample was a weighted mean over ±0.5Å, with a weight of 1.0 at the sample center, decreasing linearly to zero at ±0.5Å.

The GHRS exposure times were determined with the expectation of binning the data to lower spectral resolution to improve signal to noise. It would have been prohibitive to obtain high signal to noise per diode for the GHRS. For the first comparison, GHRS samples have been further smoothed with a boxcar filter over 15 samples, ±3.5Å.

The FOS data have been similarly composited, resampled and binned. Figure 1 compares FOS and GHRS 16 Cyg B HST spectra with a solar rocket UV spectrum by Mount and Rottman (1981), as modified by Wagener *et al.* (1985). The FOS spectrum in its uncorrected form clearly exhibits significant grating scatter at short wavelengths with respect to the other two spectra. A correction to the FOS data is also shown in Fig. 1, the method for which is described below.

There are two reasons why the flux in the uncorrected FOS spectrum apparently increases so strongly toward shorter wavelengths below 2100Å. The first is that, as the true signal decreases rapidly, the excess scattered light becomes relatively more important. The second is that the decreasing sensitivity of the FOS toward shorter wavelengths enhances the excess in the calibration process.

Less apparent in Fig. 1 is that the GHRS is also affected by grating scatter below

2100Å. Figure 2 shows a ratio of GHRS stellar and rocket solar spectra from Fig. 1. Input data for the ratio were taken directly from Fig. 1, but after the ratio was performed, the data were further binned to 8Å. There is a significant anomaly in the range 1800 – 2100Å. Below 1800Å, GHRS data are from the G140L and they are not influenced by grating scatter, because of the properties of the side 1 detector.

Further, at 2100Å it is apparent in Fig. 1 that the solar/stellar spectra begin to decrease rapidly toward shorter wavelengths. In this situation, the relative importance of grating scatter is enhanced. Figure 3 shows a similar ratio spectrum, comparing FOS stellar spectra, INCLUDING A CORRECTION FOR THE FOS GRATING SCATTER, and the solar rocket spectrum. Because of the correction, discussed below, the problem is much reduced in the FOS.

It should also be noted that the solar spectrum itself may not be without problems. Mount and Rottman (1981) used a two-detector system to cover their spectral range, 1200 – 3200Å, much as the GHRS does, with a splice between independent detectors at 1800Å. Wagener *et al.* (1985) have discussed the data of Mount and Rottman near 1800Å and proposed a modification, which is implicitly included in the solar data herein.

Furthermore, all of the criteria by which 16 Cyg B was determined to be a solar analog were applied at wavelengths above 3000Å (Hardorp, 1978).Therefore, it is entirely possible that the star and the Sun are intrinsically different in this new wavelength range.

Preliminary investigation of grating scatter within the GHRS, by comparing the small region of overlap between G140L (side 1, solar blind) and G200M (side 2) from 1800 to 1825Å in the 16 Cyg B spectra, indicates that at 1800Å, G220M data are high by about 5%. This is much less than the sharp drop at 1800Å apparent in Fig. 2. Unfortunately, the potential significance of grating scatter within the GHRS for this work was not realized until it was too late to make a full study of it in time for the SV report. Work on determining corrections for the GHRS is continuing and will be reported in the open literature.

The conclusion from Fig. 2 is that GHRS data in the range 1800 – 2100Å must be treated with some caution pending further study.

Having considered the imperfections in the data with which the FOS is being compared, we now return to the primary topic – correcting the FOS using the imperfect data.

In the HST data pipeline, at the time these data were obtained, FOS data were routinely corrected for light loss due to spherical aberration and GHRS data were not. Thus a normalization factor must be applied to the GHRS data. To put the composite GHRS spectrum and the FOS G190H spectrum on a common absolute scale, the GHRS and FOS were normalized by applying a factor of 1.45 to the GHRS data. This factor was determined using data only longward of 2150Å, where the effects of grating scatter on both spectrographs is relatively small.

When this is done, the apparent FOS signal below 2100Å is uniformly above the GHRS signal, consistent with the trends shown in Fig. 1. In the ideal case, in which the GHRS were a perfect instrument, without grating scatter, the difference between the FOS and the normalized GHRS would be due to scattered light within the FOS. Subtracting the two curves then would give the scattered light spectrum within the FOS, which may be converted from energy units to counts/second/diode using the inverse FOS calibration function. The results of such a calculation are shown in Figure 4 for the spectral range from 1570 to 1840Å which was covered by the G140L. Figure 4 also includes the pipeline FOS G190H count rate for 16 Cyg B.

The FOS calibration function is determined by measurements in which photons near the wavelength of interest are not overwhelmed by orders of magnitude by photons at other wavelengths, so grating scatter is not a problem here.

The difference between the FOS pipeline count rate and the calculated scattered light count rate in Fig. 4 is the best estimate of the true 16 Cyg B signal in the FOS data. By construction, if the difference between these two curves were converted to energy units, it would be precisely the same spectrum as the GHRS G140L spectrum below 1840Å in Fig. 1. It is suggested that this curve can be used reliably to correct future FOS G190H observations of red objects, such as planets and solar–like stars.

The procedure would be to match the G190H planetary/stellar spectrum to the simulated scattered light curve in Fig. 4 near 1580Å and subtract them. The difference would then be calibrated with the FOS calibration function, to produce a planetary/stellar spectrum for analysis. The confidence of the investigator in the quality of the result between 1600 and 1800Å would in large part be determined by the qualitative match between the simulated scattered light curve and the target observation at those wavelengths.

But it is also very clear that the process fails above 1840Å, where the input data are from G200M, which has its own grating scatter. The simulated scattered light curve above 1800Å is so noisy that it is not plotted in Fig. 4. The procedure described above could be used formally, but the result would include the GHRS grating scatter.

Rather, it is suggested that it would be better to use the pre–flight laboratory measurements of FOS scattered light by Blair *et al* above 1840Å. A smooth curve which has been fitted to these data is also shown in Fig. 4. The lab measurements are normalized to the simulated scattered light count rate between 1750 and 1840Å. This is a somewhat uncertain step, because the details of the two versions of the scattered light at wavelengths below 1750Å are not in good agreement.

In Fig. 1, the corrected FOS spectrum, constructed with the laboratory measurements of scattered light, is shown down to 1800Å. At shorter wavelengths, the preferred method, using the GHRS G140L, would, as explained above, produce a result that was literally identical to the GHRS spectrum at those wavelengths in that figure.

Figure 5 compares the corrected FOS composite spectrum (resampled but with no additional smoothing) to the GHRS composite spectrum (smoothed $\pm$ 3.5Å) in the range from 1800 to 2000Å.. The GHRS spectrum had been normalized in the region from 2150 to 3300Å(not shown in Fig. 5). Note that grating scatter in the GHRS data is indicated, because that spectrum is systematically higher than the FOS one. Note also the Si II emission lines clearly evident at 1808 and 1817Å in the FOS data.

REFERENCES

Blair, W. P., Davidsen, A. F., Uomoto, A. (1989). "Scattered Red Light in the FOS", unpublished FOS Calibration Report 058, Johns Hopkins University

Hardorp, J. (1978) "The Sun Among the Stars. I. A Search for Solar Spectral Analogs", *A.A.*, **63**, 383–390.

Mount, G. and Rottman, G. (1981), "The Solar spectral irradiance 1200–3184 A near solar maximum: July 15, 1980", *J. Geophys. Res.* **86**, 9193–9198.

Wagener, R., Caldwell, J., Owen, T., Kim, S. J., Encrenaz, T., and Combes, M. (1985). "The Jovian Stratosphere in the Ultraviolet", *Icarus* **63**, 222–236.

FIGURE CAPTIONS

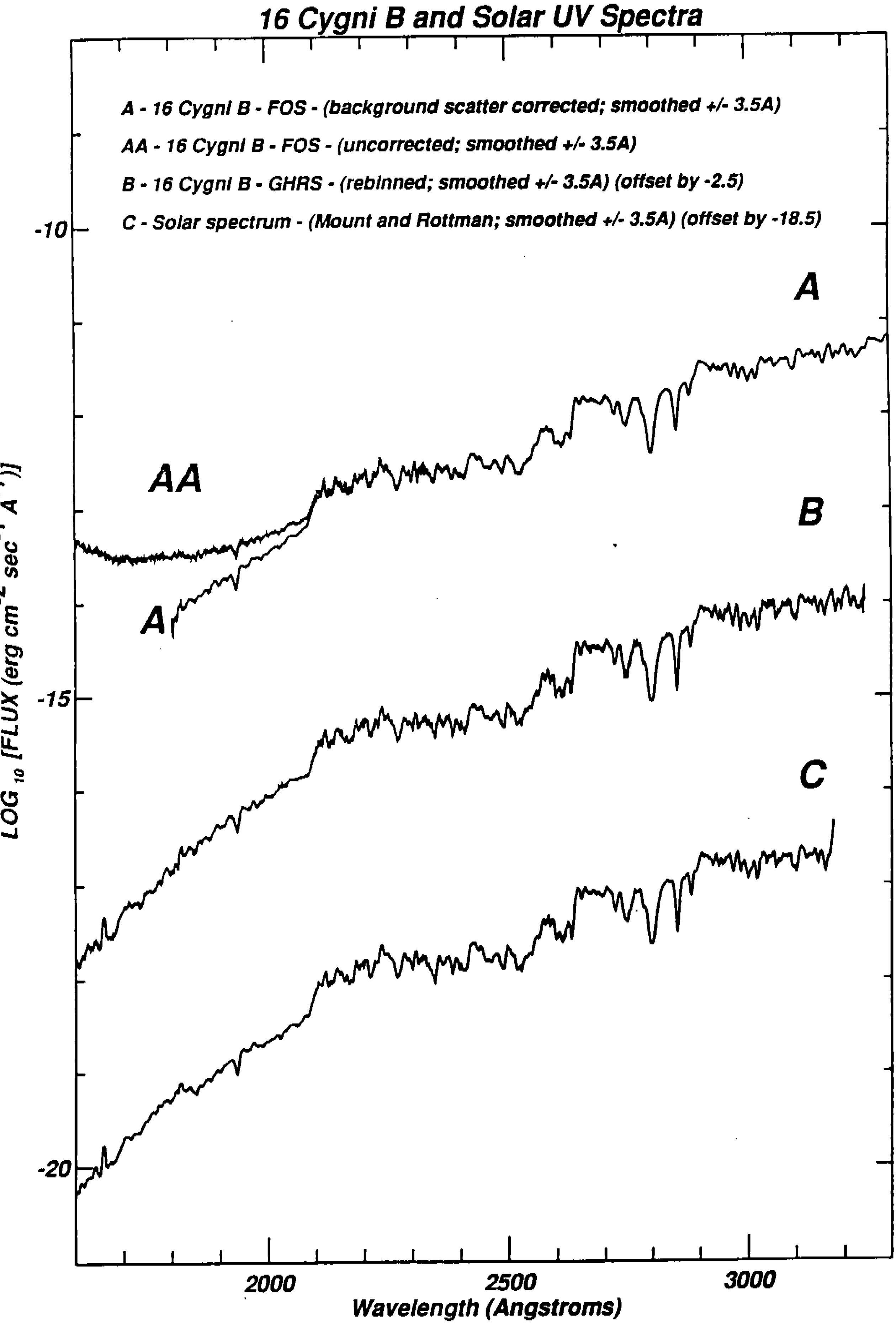
Figure 1: Comparison of FOS and GHRS 16 Cyg B HST spectra with a solar rocket UV spectrum by Mount and Rottman (1981), as modified by Wagener *et al.*. (1985). The FOS uncorrected spectrum (curve AA) is a composite of the G190H and G270H FOS observations described in Table I. Curve A is a replot of these data after a correction for grating scatter has been applied. A composite spectrum of all the GHRS spectra described in Table I is plotted as curve B. The modified Mount and Rottman (1981) solar data is plotted as curve C.

Figure 2: The ratio of GHRS stellar (curve B) and rocket solar (curve C) spectra from Fig. 1. Input data for the ratio were taken directly from Fig. 1, but after the ratio was performed, the data were further binned to ± 8Å. An anomaly is present from 1800 to 2100Å, attributable at least in part to grating scatter in GHRS G200M.

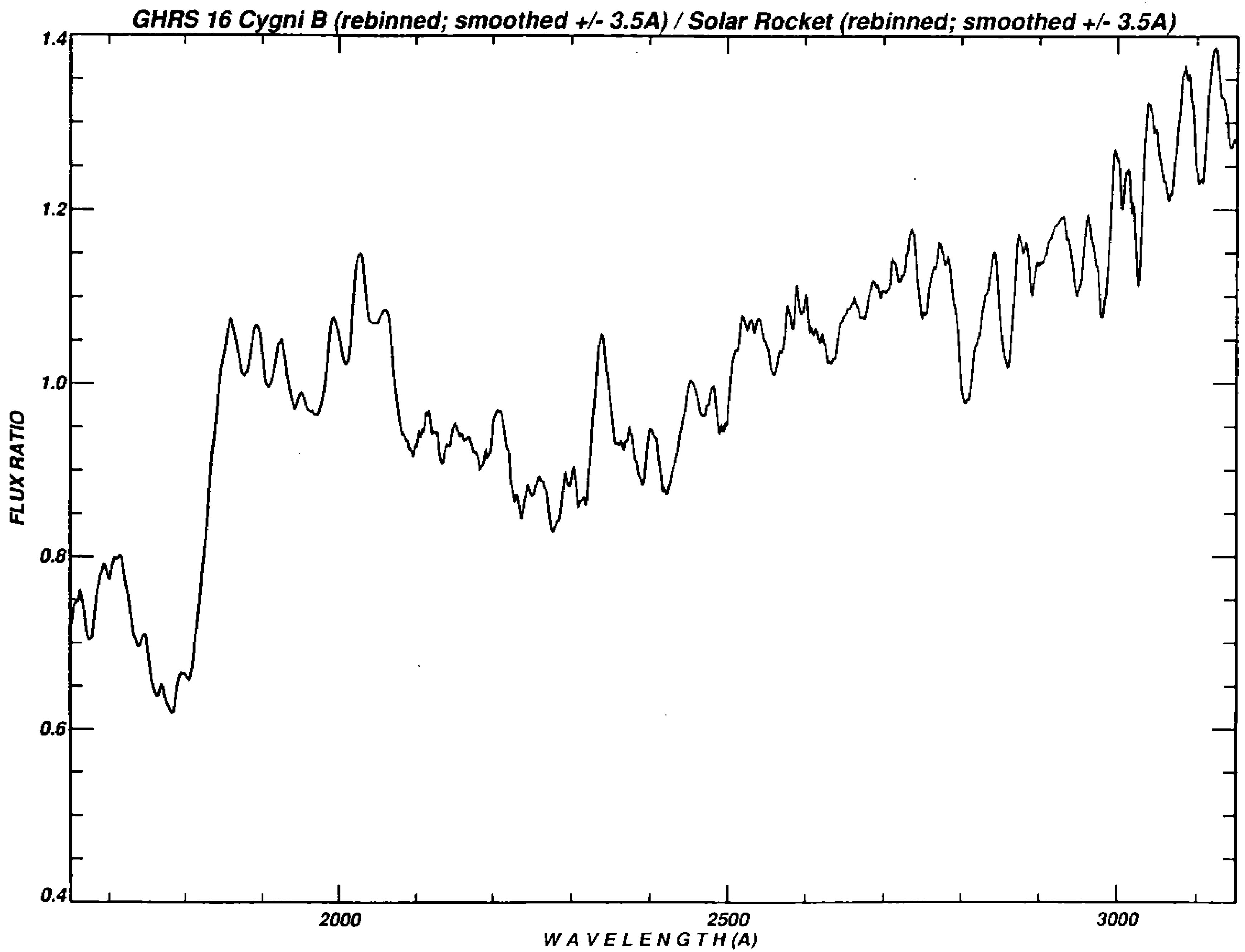
Figure 3: Identical to Fig. 2 except the corrected FOS spectrum (curve A) is ratioed to the rocket solar spectrum (curve C) from Fig. 1. As in Fig. 2 after the ratio was performed, the data were further binned to ± 8Å. Because of the correction, the ratio is better behaved in the range from 1800 to 2100Å than it was in Fig. 2. The large apparent depression in the ratio curves of both Figs. 2 and 3 just below 1800Å is in the region where Wagener *et al.*. (1985) recommended modifying the solar data, and so it might be entirely due to a problem in the solar data.

Figure 4: The various data sets used to determine the FOS G190H grating scatter background counts. The background used for correcting the FOS spectra in other figures is given by the thick solid line from 1570 to 1840Å and, above 1840Å, by the smooth curve which has been fitted to laboratory data.

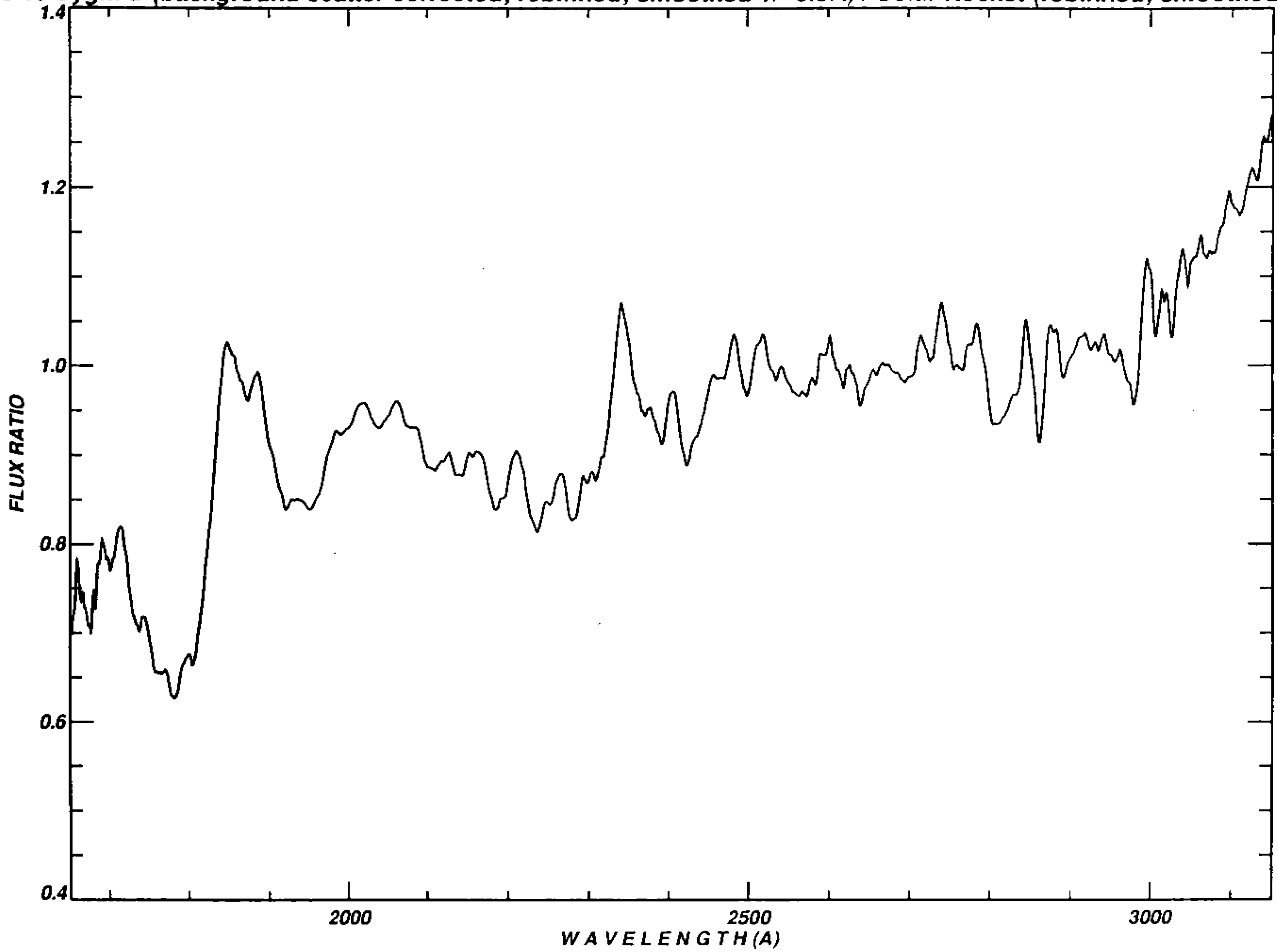
Figure 5: Comparison of the corrected FOS composite spectrum (resampled but with no additional smoothing) to the GHRS composite spectrum (smoothed ± 3.5Å). The GHRS spectrum was normalized in the region from 2150 to 3300Å. Note that some small grating scatter in the GHRS data is indicated. Note also the Si II emission lines clearly evident at 1807 and 1817Å in the FOS data.

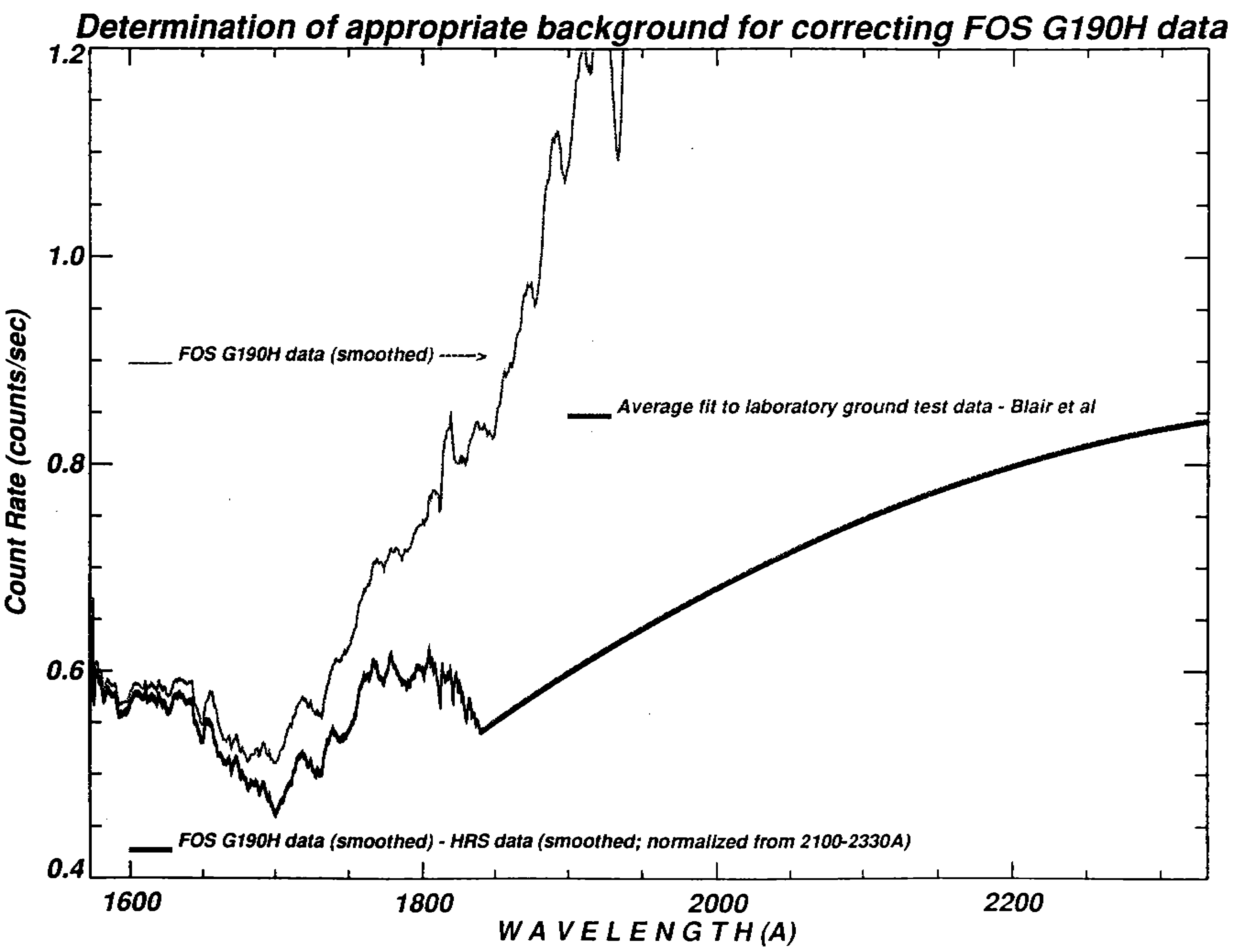

16 Cygni B and Solar UV Spectra
A - 16 Cygni B - FOS - (background scatter corrected; smoothed +/- 3.5A)
AA - 16 Cygni B - FOS - (uncorrected; smoothed +/- 3.5A)
B - 16 Cygni B - GHRS - (rebinned; smoothed +/- 3.5A) (offset by -2.5)
C - Solar spectrum - (Mount and Rottman; smoothed +/- 3.5A) (offset by -18.5)
A
AA
B
A
C
-10
-15
-20
LOG 10 [FLUX (erg cm-2 sec-1 A-1)]
2000
2500
3000
Wavelength (Angstroms)

Figure


GHRS 16 Cygni B (rebinned; smoothed +/- 3.5A) / Solar Rocket (rebinned; smoothed +/- 3.5A)
FLUX RATIO
1.4
1.2
1.0
0.8
0.6
0.4
2000
2500
3000
W A V E L E N G T H (A)

FOS 16 Cygni B (background scatter corrected; rebinned; smoothed +/- 3.5A) / Solar Rocket (rebinned; smoothed +/- 3.5A




Determination of appropriate background for correcting FOS G190H data
Count Rate (counts/sec)
1.2
1.0
0.8
0.6
0.4
FOS G190H data (smoothed) ------>
Average fit to laboratory ground test data - Blair et al
FOS G190H data (smoothed) - HRS data (smoothed; normalized from 2100-2330A)
1600
1800
2000
2200
W A V E L E N G T H (A)

GHRS 16 Cygni B (rebinned; smoothed +/- 3.5A) compared to corrected FOS G190H spectrum