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Comparison of the Low-Resolution Mode of the GHRS and the High-Resolution Modes of the FOS

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Abstract. The wavelength region between 1150 Å and 1900 Å can be observed with the GHRS and the FOS with similar spectral resolution. The advantages of using either the GHRS with the G140L grating or the FOS with the G130H and G190H gratings are discussed. We address instrumental overheads, target acquisitions, sensitivity, scattered light, wavelength coverage, aperture sizes, and spectral resolution. In general, if observations at wavelengths below 1500 Å are the prime scientific goal, the GHRS is more sensitive and has better spectral resolution. At longer wavelengths, the FOS will give better scientific return.

1. Introduction

The Servicing Mission fully restored the original Side 1 capabilities of the GHRS. In particular, the use of the low-resolution grating G140L has become possible again. This allows observations of many faint targets in the ultraviolet which could otherwise only be observed with the FOS. The observer has to decide which of the two instrument configurations — the GHRS in its low-resolution mode or the FOS in its high-resolution modes — is better suited for a particular application. In this report we compare the capabilities of the GHRS G140L grating and the FOS G130H and G190H gratings. Overheads, target acquisitions, sensitivities, and spectral resolutions are discussed for both instruments.

2. Scheduling Constraints

Typical observation sequences for the GHRS and the FOS are rather similar. In virtually all cases there will be a guide-star acquisition, a target acquisition using the onboard software, and the actual science observation. The overhead times associated with the target acquisition and the instrumental overheads (grating set-up, etc.) are nearly the same (cf. Table 1). We assumed for the examples that a simple ACQ is used for acquisition into the LSA of the GHRS and an ACQ/BINARY for acquisition into either the 4.3 or the 1.0 arcsec aperture of the FOS. Peak-up's significantly increase the overhead in both the GHRS and the FOS. (A peak-up may be required for the FOS if the target brightness is uncertain or if the target has a complex morphology).

Guide-star acquisitions are the same for both the GHRS and the FOS. After the installation of COSTAR, the GHRS and FOS apertures are within less than 2 arcmin in the V2-V3 plane. It is very likely that a guide-star pair which is usable for the GHRS would also be available for the FOS, and vice versa. Therefore using one instrument instead of the other is not an option for finding additional guide stars if observations in a sparse field suffer from the lack of suitable guide stars.

When calculating the overhead during a GHRS target acquisition, we assumed that it is actually feasible to acquire the target with the GHRS. In many cases this may not be easily possible. The G140L grating is on Side 1 which has a relatively insensitive target acquisition mirror. The problem is aggravated by a maximum integration time of less than 13 seconds which can be used per step to accumulate counts during a spiral search. In practice this means that most objects which are of interest for observations with G140L cannot be acquired on Side 1 of the GHRS. The work-around would be to use a target acquisition mirror on Side 2, which is more than an order of magnitude more sensitive because of the larger bandwidth of the Side 2 detector. This, however, invokes a 40 minute overhead (due to the switch from one detector to the other) which in most cases will force the observer to use an additional orbit for the target acquisition. In addition, the faintest targets may be too faint for a Side 2 acquisition. In the case of a faint target, one could use the FOS for a target acquisition and do a blind off-set to the GHRS. This mode is cost-efficient with little overhead. This mode is currently being studied at the Institute, and we hope to make it available for general use in Cycle 5.

To summarize, if the target can be acquired by the GHRS on Side 1, the overheads of the GHRS and the FOS are essentially the same. If Side 2 is used for the GHRS target acquisition, an additional overhead of up to 40 minutes is added (depending on what fraction of the overhead time can be charged to the occulted part of the orbit). If the FOS can be used to assist in the GHRS target acquisition, the target acquisition overhead is dominated by the corresponding overhead for the FOS.

3. Detector and Grating Characteristics

The dark counts may affect the S/N for very faint targets. The FOS and GHRS detectors have similar dark count rates of somewhat less than 0.01 counts s^{-1} diode^{-1} (see Table 1).

The spectral range accessible with the FOS extends from 1140 Å to above 8000 Å. It competes with the GHRS in the range 1150 Å to 1900 Å, which is the wavelength coverage of the G140L grating. Observations in the 1150 Å to 1900 Å range with the FOS would require a side-switch. The wavelength region below 1600 Å can only be observed with the blue side of the FOS whereas the red side is necessary at longer wavelengths. The instrumental overhead of an FOS side-switch is negligible if no additional peak-up is performed.

The wavelength dispersion (Å diode^{-1}) is 0.57 for the GHRS and 1.00 and 1.45 for the FOS+G130H and FOS+G190H, respectively. If higher spectral resolution is required, the GHRS is the instrument of choice. On the other hand, due to the higher GHRS wavelength dispersion, the accessible wavelength range per grating setting of the GHRS is only 286 Å as compared to 460 Å and 720 Å for the G130H and G190H gratings of the FOS, respectively. If wide wavelength coverage is crucial, it is more advantageous to use the FOS. Using the GHRS requires an additional grating position to achieve the same wavelength coverage as with the FOS.

The GHRS offers two apertures: the LSA (size: 1.74 × 1.74 arcsec^2) and the SSA (size: 0.22 × 0.22 arcsec^2). We expect that most faint (for the GHRS) targets will be observed with the LSA and its higher throughput. Therefore all simulations were done using the LSA. Numbers for the SSA can be obtained with appropriate scaling factors from the GHRS Instrument Handbook. The FOS has a variety of apertures. We are considering two apertures whose size is comparable to the LSA: the 4.3 aperture (actual size: 3.7×1.2 arcsec^2) and the 1.0 (actual size: 0.86 arcsec/circular). The choice between these apertures will be affected by a trade-off between sky background, size of the target, and spectral resolution (see below).

4. Sensitivity

In what follows we assume an input spectrum of $F_\lambda = 1 \times 10^{-14}$ erg s^{-1} cm^{-2} Å^{-1} that is constant at all wavelengths. Extrapolated to the V passband, this corresponds to an object having a visual magnitude of V = 13.89. In Table 2 we list the predicted count rates for this flux distribution. Grating G140L has its maximum sensitivity around 1300 Å, where 0.17 counts s^{-1} diode^{-1} are expected. (The values for the GHRS have to be divided by about a factor of two at all wavelengths for point source observations if the SSA is used). The GHRS count rates can be compared to the FOS values. The results for the 4.3 and 1.0 apertures are given. They differ by only about 9% on average, indicating that the 1.0 aperture includes essentially the entire PSF of a point source. The FOS count rates increase sharply longward of 1600 Å. This is due to the higher sensitivity of the FOS red side, which was used for the calculations. The count rates for the three cases in Table 2 are plotted in Figure 1.

Table 2 and Figure 1 demonstrate that the low-resolution grating of the GHRS is more sensitive than the high-resolution grating of the FOS at the shortest wavelengths. For instance, at 1300 Å GHRS+G140L+LSA produces a count rate which is 3 times higher than for FOS+G130H+1.0. At the longest wavelengths the situation reverses. FOS+G190H+1.0 is 70 times more sensitive than GHRS+G140L+LSA at 1800 Å. If the observations are done with G190H on the blue side of the FOS, the comparison is less favorable for the FOS but even then the GHRS would be about an order of magnitude less sensitive than the FOS between 1700 Å and 1900 Å.

The two instrument/grating/aperture combinations have the same sensitivity around 1500 Å. As a guide-line for planning observations, we recommend that the GHRS is the instrument of choice if the wavelength region of prime interest is below 1500 Å, whereas the

FOS is better suited above 1600 Å. Of course, other factors such as aperture size, spectral resolution and wavelength coverage will also affect the decision, and the observer must take the trade-offs into account.

5. Scattered Light

The FOS dispersers are known to suffer from significant grating scattered light due to the extended red sensitivity of both the FOS red and blue detectors. Photons with wavelengths longer than 2000 Å are detected in the wavelength range covered by the G130H grating. Scattered light is usually not a problem when blue stars are observed, but becomes significant in observations of late-type stars (or objects with similar flux distribution) taken in the 1150 – 2100 Å region. As an example, Figure 2 shows the FOS blue side spectrum of the solar analogue 16 Cyg B together with the true intrinsic spectrum. Table 4, from Appendix C of the FOS Handbook, gives logarithmic ratios of count rates (scattered + intrinsic)/(intrinsic) for three late-type stars. At the shortest wavelengths, the FOS spectra become dominated by scattered light.

In contrast, the G140L grating of the GHRS is not affected by scattered light.

6. Spectral Resolution

In Table 3 we give the expected spectral resolution for several instrument configurations. Two limiting cases are considered: observations of a point source and of an extended source uniformly filling the aperture. The second case will be of interest for observations of extended targets which probably fall in between the two extreme cases of a point source and a uniform source filling the aperture.

We begin with a point source. Use of the LSA degrades the resolution of the GHRS from its 1 diode value to about 1.25 diodes, resulting in a spectral resolution of 0.7 Å. This is a factor of 1.5 and 2 better than for FOS+G130H and FOS+G190H, respectively. If the SSA of the GHRS were used, the GHRS would retain its full 1 diode resolution of 0.57 Å.

If the apertures are uniformly filled by the source, the spectral resolution critically depends on the aperture size, which determines how many diodes are illuminated simultaneously. In the case of the GHRS Large Science Aperture this leads to a degradation by a factor of 8 relative to the case of a point source observed with the SSA. The spectral resolution will be about 4.6 Å. Similar arguments hold for the FOS. Use of the 4.3 aperture results in very poor spectral resolution of less than 10 Å, which in most cases will not be acceptable scientifically. In contrast, observations of extended objects will suffer a spectral resolution degradation by only a factor of ~2.5 (as compared to point source observations) when the 1.0 aperture of the FOS is used.

In summary, we find that the GHRS+G140L+LSA offers a spectral resolution which is always better by a factor of 1.5 – 2 than the FOS values for point sources. In the case of extended sources, the 1.0 aperture of the FOS provides better spectral resolution. The 4.3 aperture — if uniformly illuminated — produces significant resolution degradation and has probably only few applications.

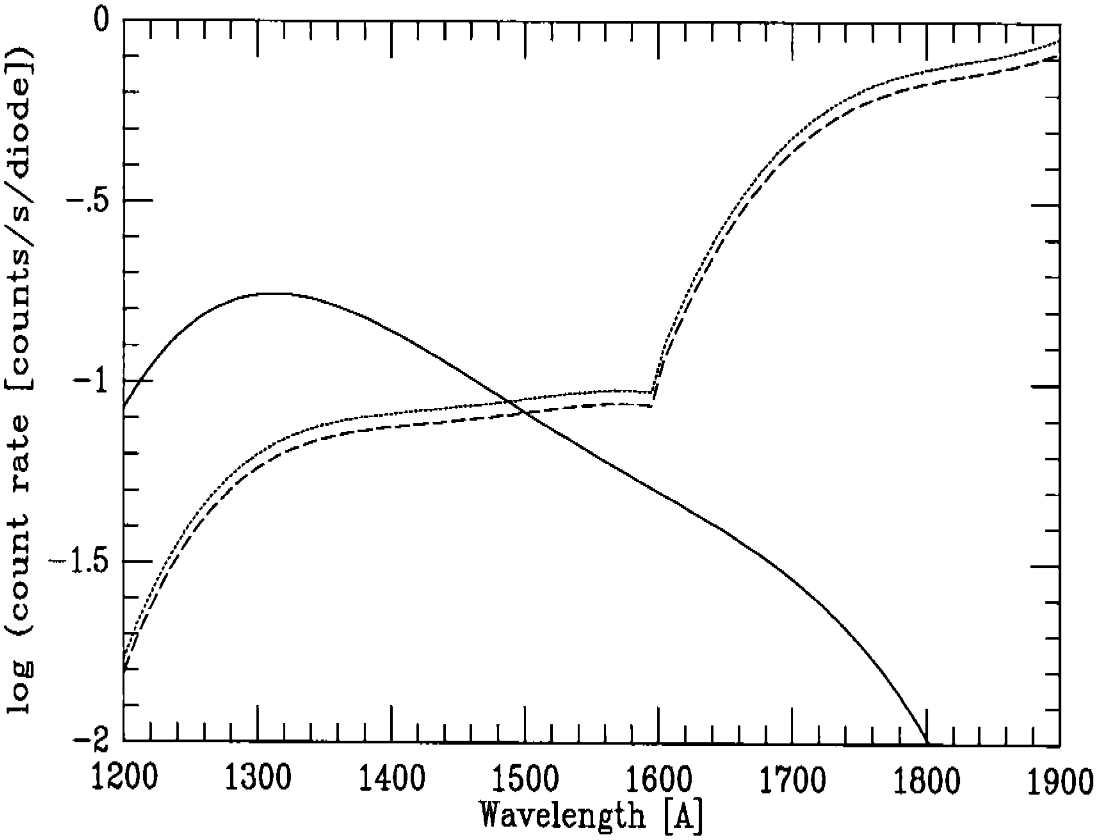
If accurate wavelengths are required, observers should keep in mind that the GHRS offers the possibility of additional onboard wavelength calibrations. This allows the observer to take full advantage of the good spectral resolution of the GHRS. With only a modest increase of overhead, an additional wavelength calibration leads to a precision of 0.2 diodes in wavelength determination. No onboard wavelength calibration is possible with the FOS.

7. Summary

No general recipe applying to all observations can be given. Therefore we highlight the advantages and disadvantages of the GHRS+G140L versus the FOS+G130H/G190H to help the observer plan her/his strategy.

- **Target acquisition.** Presently the GHRS has only limited target acquisition capabilities for faint targets on Side 1. In many cases it will be possible to use Side 2 for target acquisition — at the cost of additional overhead. It is planned to make the FOS available to assist in the GHRS target acquisition. When this mode is in place, GHRS and FOS will have the same target acquisition capabilities and comparable overheads.
- **Aperture size.** The FOS offers a wider range of aperture sizes than the GHRS. However, the LSA of the GHRS should be acceptable for most scientific applications.
- **Wavelength coverage.** The GHRS has smaller wavelength coverage per grating setting than the FOS. Complete coverage of the 1150 Å – 1900 Å region requires 3 grating positions with the GHRS. The same coverage can be achieved by the FOS with 2 settings involving, however, a side-switch.
- **Wavelength calibration.** The GHRS allows precise wavelength calibrations to within 1/8 diode with an onboard spectral calibration. This capability does not exist for the FOS.
- **Sensitivity.** The GHRS is more sensitive at the shortest wavelengths. The FOS is much more sensitive at the longest wavelengths. The turn-over wavelength is at 1500 Å.
- **Scattered light.** FOS observations of red objects which are observed at the shortest ultraviolet wavelengths suffer from scattered light. This problem does not exist for the GHRS.
- **Spectral resolution.** Observations of point sources have better spectral resolution with the GHRS. The spectral resolution of extended objects critically depends on the aperture size. The GHRS LSA is intermediate in resolution between the FOS 4.3 and 1.0 apertures.

Figure 1. Count rates versus wavelength for the three grating/aperture combinations of Table 2. Solid line: GHRS+LSA; dotted: FOS+4.3; dashed: FOS+1.0. The FOS count rates are for the blue and red side below and above 1600 Å, respectively.



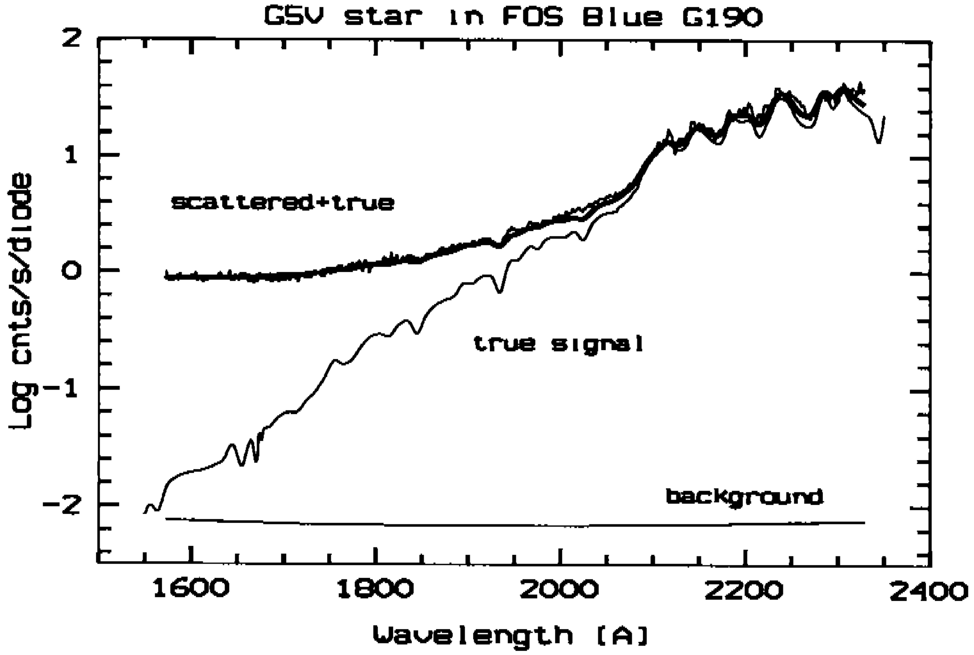


Figure 2. FOS blue G190H data for the G5 V star 16 Cyg B. The count rate spectrum due to intrinsic photons and the composite spectrum of intrinsic plus scattered photons are overlaid (Rosa, Appendix C, FOS Instrument Handbook, 1994)

Table 1: General characteristics of the GHRS+G140L, FOS+G130H, and FOS+G190H. G130H is on the blue side, and G190H on the red side of the FOS.

	GHRS+G140L	FOS+G130H	FOS+G190H
Target Acquisition Overheads [minutes]	11	9	9
Instrumental Overheads [minutes]	4	6	6
Dark Count Rate [counts s^{-1} $diode^{-1}$]	0.005	0.007	0.010
Wavelength Coverage [Å]	1150 – 1900	1140 – 1600	1590 – 2310
$\Delta\lambda$ [Å $diode^{-1}$]	0.57	1.00	1.45
Wavelength Range per Setting [Å]	286	460	720
Aperture Size [arcsec]	1.74 x 1.74	3.7 x 1.2, 0.86	3.7 x 1.2, 0.86

Table 2: Expected count rates for the GHRS+LSA and the FOS with the 4.3 and 1.0 apertures. The FOS count rates for wavelengths at and below 1600 Å are for G130H on the blue side. Above 1600 Å G190H on the red side was used. Input spectrum: point source with $F_\lambda = 1 \times 10^{-14}$ erg s^{-1} cm^{-2} $Å^{-1}$.

Wavelength	GHRS+LSA	FOS+4.3	FOS+1.0
[Å]	counts s^{-1} $diode^{-1}$		
1200	8.5×10^{-2}	1.7×10^{-2}	1.6×10^{-2}
1300	1.7×10^{-1}	6.3×10^{-2}	5.8×10^{-2}
1400	1.4×10^{-1}	8.2×10^{-2}	7.5×10^{-2}
1500	8.9×10^{-2}	9.0×10^{-2}	8.3×10^{-2}
1600	4.4×10^{-2}	9.4×10^{-2}	8.6×10^{-2}
1700	3.2×10^{-2}	4.8×10^{-1}	4.4×10^{-1}
1800	1.0×10^{-2}	7.4×10^{-1}	6.8×10^{-1}
1900	1.1×10^{-3}	9.0×10^{-1}	8.3×10^{-1}

Table 3: Spectral resolution [Å] for different grating/aperture combinations. The extended source is assumed to uniformly fill the aperture.

	Point source	Extended source
GHRS+G140L+LSA	0.7	4.6
FOS+G130H+4.3	0.96	12.2
FOS+G130H+1.0	0.96	2.29
FOS+G190H+4.3	1.40	17.7
FOS+G190H+1.0	1.40	3.32

Table 4: Logarithmic ratios of count rates (scattered + intrinsic)/(intrinsic) for unreddened stars. FOS, blue detector.

A0 V G130H		G5 V G190H		K3 III G270H	
λ	$\log \frac{S+I}{I}$	λ	$\log \frac{S+I}{I}$	λ	$\log \frac{S+I}{I}$
1170	0.98	1600	2.92	2250	1.49
1215	1.73	1700	1.00	2350	1.15
1250	0.18	1800	0.41	2500	0.52
1300	0.02	1900	0.19	2700	0.24
1400	0.01	2000	0.07	3000	0.02
1600	0.00	2300	0.01	3300	0.00