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Scattered Light in the G130H & G190H Modes of the HST Faint Object Spectrograph

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Abstract. Grating scattered light can be a significant problem for FOS spectroscopy of "red" celestial objects below 2000 Å. It can be quantified empirically through comparisons of G130H and G190H spectra of solar-type stars with templates based on irradiance scans of the Sun and IUE exposures of field G-type dwarfs.

1. Introduction

The Hubble Space Telescope (HST) has opened new frontiers in the study of the far-ultraviolet (FUV) spectra of a diversity of cosmic objects, ranging from nearby planets to distant Active Galactic Nuclei. Late-type stars similar to the Sun particularly benefit from scrutiny in the sub-2000 Å FUV range, because it harbors key emissions – like C IV $\lambda\lambda$1548,50 and N V $\lambda\lambda$1238,41 – arising in the high-excitation (10^5 K) subcoronal layers (e.g., Linsky, Brown, & Carpenter 1991). While the venerable *International Ultraviolet Explorer* (IUE) has contributed greatly to the understanding of the puzzling hot outer atmospheres of cool stars (e.g., Jordan & Linsky 1987), its limited sensitivity has confined its gaze to bright, mostly nearby, field stars. The HST/FOS can reach much further, with higher spectral resolution and a sensitive pulse-counting detector system.

For example, a recent study of the young solar-type star HII 314 in the Pleiades cluster with FOS grating G130H (1150–1606 Å) and the BLUE Digicon (Ayres et al. 1993a) yielded positive ($> 5\sigma$) detections of the C IV blend in *each* of twenty-one 4.2-minute readouts at an average integrated flux level of about 1.5×10^{-14} ergs cm^{-2} s^{-1}. In contrast, the 5σ limiting C IV flux in a *full-shift* ($\approx$ 420 minute) SWP-LO exposure already is a factor of three higher.

On the other hand, the FOS dispersers are known to suffer from significant grating scattered light (Caldwell & Cunningham 1992), a problem made worse for the faint FUV emissions of late-type stars by the extended red response of the BLUE detector (the scattered photons mostly are from the bright continuum regions longward of 2000 Å). Here, I describe a set of FOS FUV spectra, obtained in a study of the subcoronal activity of solar-type stars in young Galactic clusters, for which the scattered light is quite evident. I demonstrate the magnitude of the problem by reference to recent FUV irradiance scans of the Sun, and IUE SWP-LO exposures of G-type field stars. Finally, I discuss the implications for future observations of red objects with the FOS.

2. The Sample

Table 1 lists the targets and FOS exposures used in the analysis. The stars are of similar spectral type (G0–G2) to the Sun, and are located in three nearby Galactic clusters ranging in age from about 1/6-th the Sun (Hyades) to less than 1/60-th (Pleiades, α Persei). All of the exposures were taken through the large (4.″3 square) A-1 aperture.

TABLE 1
HST/FOS OBSERVATIONS OF CLUSTER G DWARFS

Targets	$< V >$ (mag)	<Sp. Typ.>	Exposure Times[a] (ksec) G130H	G190H	G270H
Hyades ($d = 45$ pc; age= 600 Myr)					
HD 25825, 26767, 27835, 28344, 28992	+8.0	G1±1 V	1.65	0.93	0.05
Pleiades ($d = 130$ pc; age= 70 Myr)					
HII 314, 996, 1514	+10.5	G0±0 V	5.34	–	0.30
α Persei ($d = 170$ pc; age= 50 Myr)					
HE 350	+11.0	G0 V	5.34	–	0.30

[a] BLUE Digicon; A-1 aperture.

Following target aquisition, a short (50–300 second) integration with grating G270H (2222–3301 Å) was obtained. In each case the λ3000 continuum flux was normal, indicating that the image was adequately centered in the aperture. Subsequently a deep (27.5–89 minute) observation of the 1150–1606 Å interval at 2 Å resolution was taken with grating G130H. The fainter Pleiades and α Per stars were recorded over three consecutive orbits in 1780-second segments. The brighter Hyads were recorded in single orbits. In addition, each of the five Hyads was exposed with G190H (1573–2330 Å) for 15.5 minutes.

The G130H traces are dominated by diffuse sky-background emissions of H I (Lyα) and O I (1302 Å); the latter is prominent only during the satellite day. Weak stellar C IV (1549 Å doublet) emission is visible in each orbit on the active stars HII 314 and HE 350, while Si IV (1400 Å doublet) and C II (1335 Å multiplet) are seen in the total observations. Indeed, HII 314 *flared* in C IV during the final of its three orbits (Ayres et al. 1993a).

Figure 1 summarizes the $\lambda < 2200$ Å spectra obtained so far in the program. In the G130H panel, the 5 Hyads have been coadded as one group (lower tracing); the 3 Pleiads and 1 α Per star constitute the other group (upper tracing). In G190H, only the Hyads were recorded. The fluxes were adjusted to $V = 0$ to permit a fair comparison between the nearby Hyades and the other two – more distant – clusters.

The dramatic curvature of the G130H spectra towards shorter wavelengths is the signature of a strong scattered light component.

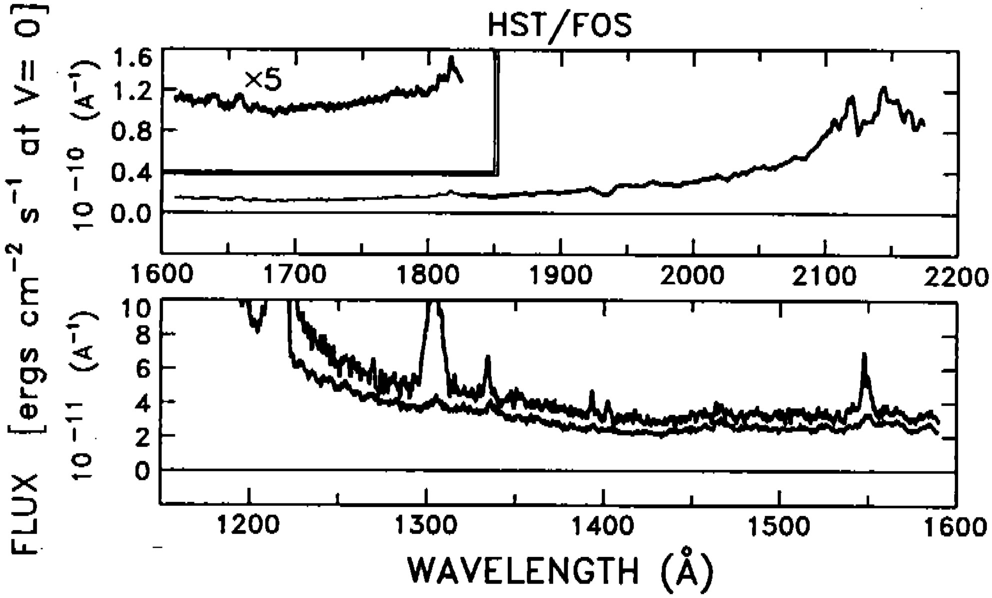

Figure 1. G190H (upper panel) and G130H (lower panel) spectra.

3. Analysis

A comprehensive discussion of the scattered light properties of diffraction gratings has been given by Woods et al. (1993: WWRH). An earlier semiempirical study – focussing on the IUE SWP low-dispersion mode – was presented by Basri, Clarke, & Haisch (1985: BCH). Caldwell & Cunningham (1992) have described the scattering levels of some of the FOS gratings, although no information was available at the time concerning the key G130H disperser.

WWRH characterize the grating scatter in terms of a Lorentzian component, which depends on the quality of the grooves and the accuracy of their spacing, and a constant background component, which derives from microscopic suface imperfections. Given measurements of the scattering profile of a grating, WWRH provide a strategy for calculating a correction matrix to restore the original flux distribution (see also BCH).

On the one hand, the scattering levels of the FOS gratings for the solar-type stars are substantial enough that a sophisticated correction algorithm is not warranted, at least in the situation where one primarily is interested in the integrated fluxes of prominent emission features. One simply can dispatch the scattered light by fitting, and subtracting, a smooth "continuum" – preferably to the original count spectrum prior to fluxing.

On the other hand, it is important to have a way to estimate the expected scattered light level *prior* to the FOS observations, so that one can compensate for the additional photometric noise contributed by the background light. In particular, if a target emission line – say, C IV – has a small contrast, $\gamma \equiv f_L/f_B$, with respect to the scattered light level ("B"), the exposure time must be lengthened by a factor of $1+\gamma^{-1}$ to achieve the same peak S/N as would obtain without the scattered light background. For example, I had calculated exposure times for the Hyads without accounting for scattered light (a problem not appreciated at the time). Given that γ is only about 20% for the key C IV feature, and correspondingly smaller for the other important but fainter emissions of the G130H interval, I should have exposed a factor of at least *six* deeper to achieve the originally desired S/N.

Accordingly, I will present a purely empirical discussion of the FOS scattered light suitable for planning observations of solar-type stars, without delving into the details of the WWRH correction algorithm. In order to derive the scattered light level empirically, one requires a reference source which has been observed by the FOS, and whose absolute energy distribution is known.

Here, I have the nine sets of FOS observations of solar-type stars: the obvious reference is the Sun itself. In particular, since fall 1991 the SOLar-STellar Irradiance Comparison Experiment (SOLSTICE: Rottman, Woods, & Sparn 1993) on the Upper Atmospheric Research Satellite has been obtaining high-S/N spectra of the Sun over the FOS interval at comparable spectral resolution. The shortwavelength "G" channel (1150–1900 Å) of SOLSTICE has a solar-blind photocathode, and thus is relatively immune to the scattering that plagues the broadband Digicons of the FOS.

However, the stars of the Cluster program are much more active than the Sun, and their FUV continuum energy distributions might be enhanced according to the higher levels of mechanical heating in their outer photospheres (e.g., Böhm-Vitense & Mena-Werth 1991). Thus, I supplemented the SOLSTICE spectra with continuum traces taken from IUE SWP-LO exposures of G-type dwarfs covering a wide range of coronal activity levels. The IUE tracings are from the ROSAT/IUE All-Sky Survey program (Ayres et al. 1993b). The SWP-LO scattered light was corrected by reference to the average instrumental counts shortward of the detector window cutoff at 1150 Å: the scattering was assumed to be independent of wavelength.

Figure 2 compares the SOLSTICE spectrum (for a day of high activity near the peak of Solar Cycle 22: full-drawn curve) with the continuum traces of three active G dwarfs and three quiet ones (dotted curves). The SOLSTICE spectrum was smoothed to the resolution of the FOS using a simulated point response function. The comparison spectra have been adjusted to $V = 0$ and multiplied by the FOS sensitivity curves to yield cnts s^{-1} (substep bin)$^{-1}$.

Note in Fig. 2 that the "quiet" IUE stars appear to have excess continuum flux compared with the SOLSTICE reference spectrum longward of about 1400 Å. Part of the discrepancy might be tracable to differences in the radiometric calibrations; part might be due to the slightly earlier spectral types of the IUE "quiet" stars compared with the Sun; and part likely can be accounted by an underestimate of the IUE scattered light correction (particularly given that it was assumed to be wavelength-independent). I fitted a smooth curve (dashed in Fig. 2) through the three active-star continua to serve as a template.

Figure 3 compares the "de-calibrated" FOS spectra of Fig. 1 to the active star template illustrated in Fig. 2 (note the change of scale in the lower panel). The shaded areas correspond to the differences between the FOS spectra and the template (barely visible in the lower panel), and thus approximate the scattered light component. The empirical scattering appears to be slightly smaller for the Hyads, consistent with their slightly redder spectral classes (and hence less

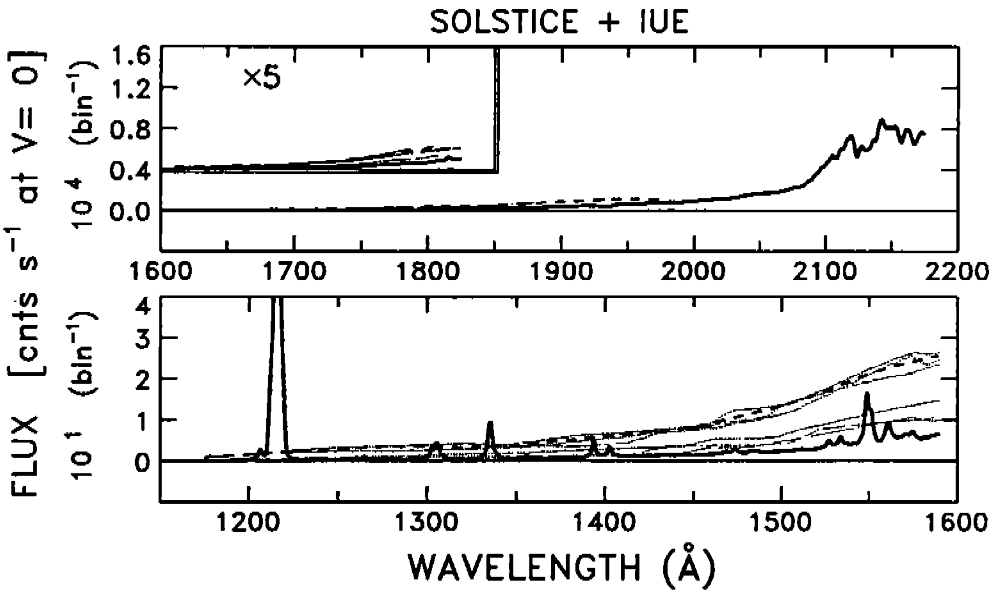

Figure 2. Solar and stellar FUV reference spectra.

mid-UV continuum flux to scatter to shorter wavelengths).

4. Conclusions

As can be seen in Fig. 3, the scattered light is approximately 400 cnts s^{-1} bin^{-1} for a $V = 0$ G0 dwarf throughout the G130H interval (rising slightly towards longer wavelengths beyond about 1400 Å), *and* at the shortwavelength end of the G190H interval (perhaps falling slightly towards longer wavelengths). The similarity in the scattering levels must be due to the physical similarity of the gratings, and the fact that the major reservoir of scatterable photons lies redward of, but close to, both intervals (i.e., $\lambda > 2100$ Å). As one considers progressively cooler stars, the scattered light level (normalized to $V = 0$) will decline owing to the rapid fading of the mid-UV continuum. As one considers progressively hotter stars, the scattered light will become worse as the wall of photospheric UV emission (visible here for $\lambda > 2100$ Å) marches progressively towards shorter wavelengths. However, the scattered light only is a problem on the blueward side of the emission jump. Of course, flat(ish)-spectrum objects like hot stars and BL Lac's will be affected hardly at all. Thus, only in the event that one has the temerity (and blessings of the TAC) to observe solar-type stars, would one have to consider the rather unpleasant (in terms of increased exposure time) effects of the scattered light in the FOS FUV gratings. Indeed, the existence of the effect emphasizes the importance of solar-blind detectors (such as Side 1 of the HST/GHRS) in FUV spectroscopy of red objects.

Acknowledgments. This work was supported by HST/GO grants from NASA, based on observations with the NASA/ESA *Hubble Space Telescope*, obtained at the Space Telescope Science Institute, which is operated by the As-

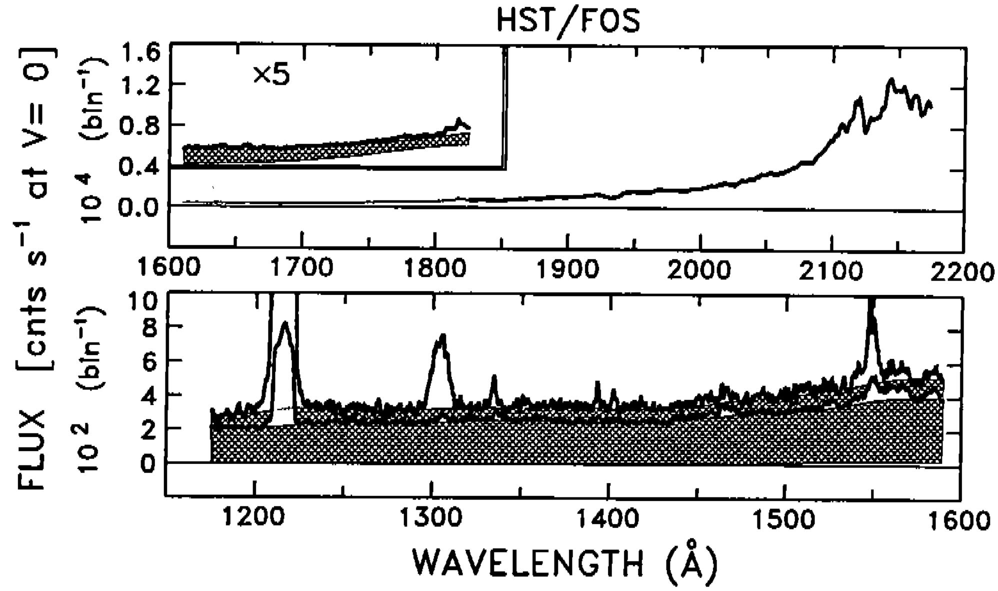

Figure 3. Empirical scattered light levels.

sociation of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. I thank G. J. Rottman for providing the SOLSTICE spectrum of the active Sun.

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