Ultraviolet Calibration Issues in the Faint Object Spectrograph

Cindy C. Cunningham[1], Christopher D. Barnet[1] and John J. Caldwell[1,2]

Abstract

A collection of planetary spectra obtained with the *HST* Faint Object Spectrograph (FOS) and the Goddard High Resolution Spectrograph (GHRS) illustrates a variety of calibration issues relevant to ultraviolet observations of extended objects with the FOS. Observations of extended objects that overfill the aperture are relevant to planetary astronomers but are not exclusive to this community. This paper concentrates on calibration questions. Evidence for small misalignments of diodes to apertures (either electronic or physical) in both spectrographs will be discussed. Second, an anomalous observation of Saturn is reported.

I. Introduction

The unique aspect of the data sets presented here is that several *HST* instruments (the FOS, the GHRS and the WFPC) were used to derive complementary information on the albedos of the outer planets. This has provided an internal check on the calibrations of the various instruments.

The most consistent data set is the Jupiter observations obtained in May 1992. Both GHRS and FOS observations were made in the short time period of a few days. After all appropriate corrections to the data have been made the GHRS and FOS observations agree well. These observations also agree well with earlier *IUE* observations – confirming a general result that, over the Jovian disk, albedo differences are small compared to uncertainties in calibration.

Observations using the FOS 1.0 and 0.3 arcsec apertures of Uranus and Neptune in June and August 1992, respectively, give planetary albedos that agree well with one another. Comparisons to *IUE* observations of whole disk measurements of these planets suggest less perfect agreement than in the comparisons of *HST* and *IUE* albedos of Jupiter. The discrepancies between *IUE* and *HST* could be a result of real changes in the albedos of these objects and calibration and limb darkening effects. Since there are no simultaneous GHRS observations of Uranus or Neptune, comparisons between *HST* instruments is impossible.

The most puzzling issue arises from observations of Saturn during December 7-12, 1992, when the planet was studied with the Planetary Camera as well as the

1. Space Astrophysics Laboratory, Institute for Space and Terrestrial Science, 4850 Keele St., North York, ONT M3J 3K1
2. Also at Department of Physics, York University.

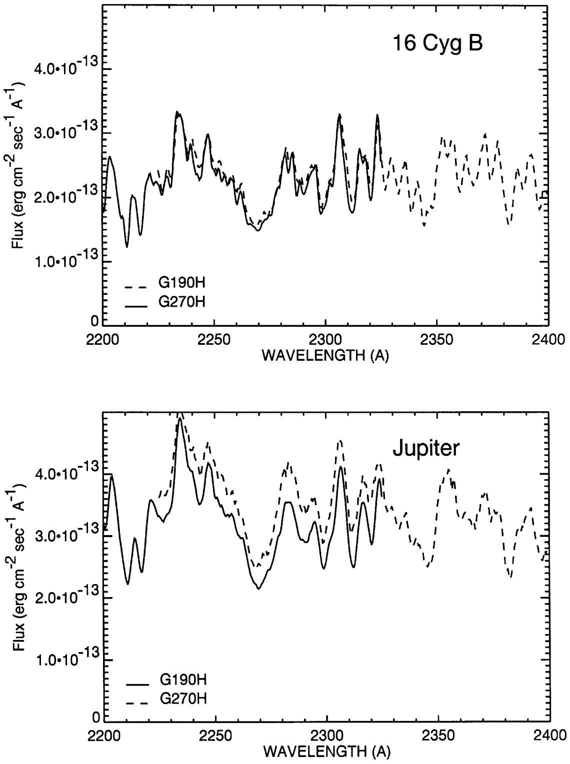

Figure 1: Comparison of FOS G190H and G270H overlap region for a stellar observation and an extended object observation (Jupiter) that overfills the aperture.

GHRS, and the FOS. The WFPC and the GHRS observations bracket the FOS G190H and G270H observations in wavelength (the GHRS spectra overlap with the low wavelength limit of the FOS; the bandcenter of the WFPC image, taken with the F336W filter, overlaps with the high wavelength limit of the FOS). There is excellent agreement between earlier *IUE* albedo measurements and the GHRS albedo values and with the WFPC albedos for 3 regions on the planet (equatorial central meridian, equatorial limb, and central meridian north pole). FOS observations for these same 3 regions are all low compared to the GHRS and WFPC albedos by a factor of 2. This is very difficult to understand unless there has been some unrecognized error in pointing or in recorded integration times of the FOS. Since Saturn subtends 15 arcsecs in the sky, pointing errors of more than 7 arcsecs would be required. Further, we cannot imagine an offset error which could offset all three observations (i.e. equatorial central meridian, north pole central meridian, and equatorial limb) in the same manner and retain the same relative scaling factor.

The second topic of concern that is addressed in this paper uses the same data set described above in combination with some observations of Titan and a solar analogue star, 16 Cyg B. Titan and the star do not overfill the aperture, while the outer planet observations do. The region of overlap between the G190H and the G270H gratings of the FOS suggest that in cases where the object overfills the aperture, there is a 10 percent disagreement in the corrected flux levels, while the corrected flux levels of objects that underfill the aperture produce very good overlap between these two grating settings, see Figure 1.

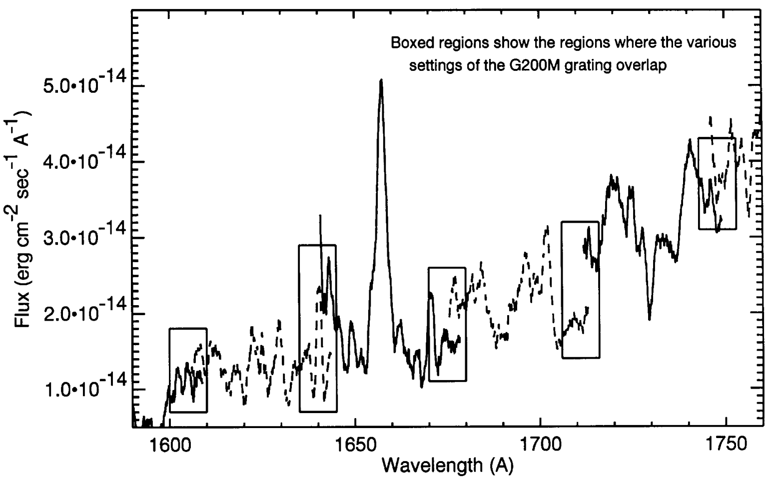

Figure 2: Comparison of overlapping G200M GHRS spectra of Jupiter .

A similar effect is noticed between overlapping grating settings of the G200M grating for GHRS observations of Jupiter (Figure 2) and Saturn.

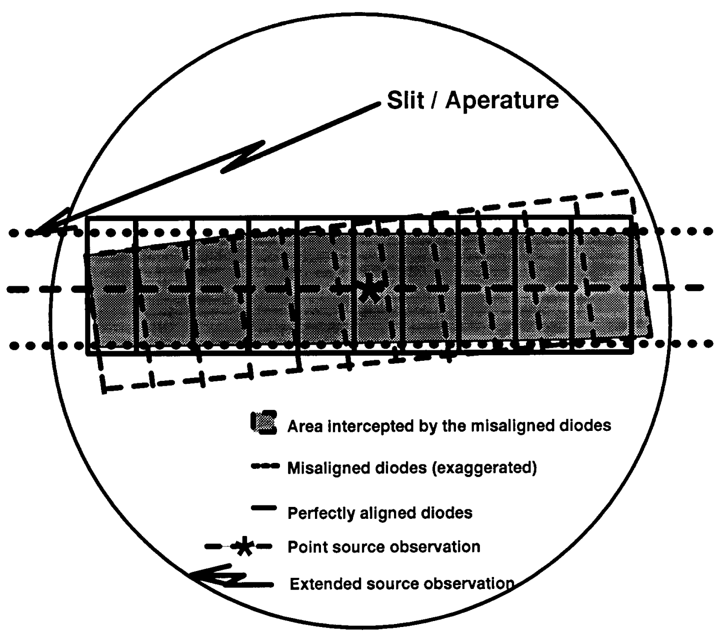

Figure 3: This figure provides one possible case of a physical misalignment of diodes and aperture that could lead to the poor overlap between spectra from different gratings that sample, the same wavelength region at opposite ends of the diode array . For a point source with reasonable centering on the aperture small misalignments do not affect the total recorded photon flux as all the light from the core of the star falls in the shaded region which marks the diode area which is intersected by the aperture. In the case where the object overfills the aperture the area of the intercepting diodes is slightly less at the left end of the diode array than it is at the right end. The schematic is deliberately exaggerated to illustrate how this effect would only be noticed when examining the grating overlap region for an extended object observation.

These overlapping wavelength regions contain valuable information on the calibration and internal alignment of components in the various instruments used (Figure 3).

II. Observations and Results

The observational data sets used for addressing the calibration issues described above are summarized in Table 1. In the case of extended objects the spherical aberration correction performed automatically by the pipeline processing must be undone because the object fills the aperture and therefore there is no loss of light. The scaling factors for the various FOS aperture sizes and gratings are tabulated in the FOS Instrument Report CAL/FOS-077 by Neill, Bohlin and Hartig (1992). The solar spectrum used to determine the planetary albedo curves is from SUSIM (Van Hoosier et al., 1988) and the solar scaling factor is calculated from:

$$S = \frac{\Omega\,(r^2)\,F_s}{\pi} \tag{1}$$

where S is the solar scaling factor given in Table 1, Ω is the solid angle of the aperture, r is the Sun - planet distance, and F_s is the solar flux at 1 AU.

Planet, Aperture & Aperture pos'n	Observing Parameters	Aperture Name - Size	Effective Aperture Area	Constant to undo spher. aberration correction *	Solar Scaling Factor	Comparison to IUE
Jupiter 1) Eq CM - B3 2) Eq CM - C2 3) Eq Limb - B3	May 13-14, 1992 1 & 2 - both G190H & G270H 3 - G190H only	B3 - 1.0" C2 - 0.25"x 2.0"	0.70 sq arcsec 0.36 sq arcsec	C2 G190H & G270H - 0.27 B3 G190H- 0.46 G270H - 0.50	5.17 E +12	Very Good
Saturn 1) Eq CM - B3 2) Eq Limb - B3 3) NP CM - B3	Dec. 8, 1992 1,2, & 3 - both G190H & G270H	B3 - 1.0"	0.70 sq arcsec	B3 G190H- 0.46 G270H - 0.50	1.73 E +14	Poor - all 3 albedos are low by factor of 2
Titan Whole disk A1 - 2 x G270H 1 x G190H	G190H - Aug,25 1992. G270H - Oct 9, 1991 & Sept 20, 1993	A1 - 4.3" B3 - 1.0" (Sept 20, 1993)	Titan smaller than aperture. Titan radius used 2935 km.	No undoing performed	1.88 E +13	Aug - off by factor of 1.4 Sept - off by factor of 1.7
Uranus Center of disk 1) B3 2) B2	June 22, 1992 1 & 2 - both G190H & G270H	B3 - 1.0" B2 - 0.3"	0.70 sq arcsec 0.053 sq arcsec	B3 G190H- 0.46 G270H - 0.50 B2 G190H & G270H - 0.17	9.30 E +14	Very Good
Neptune Center of disk 1) B3 2) B2	Aug 19, 1992 1 & 2 - both G190H & G270H	B3 - 1.0" B2 - 0.3"	0.70 sq arcsec 0.053 sq arcsec	B3 G190H- 0.46 G270H - 0.50 B2 G190H & G270H - 0.17	1.73 E +14	All albedos were low by a factor of 1.4

* Photometric Calibration of the Faint Object Spectrograph - J.D. Neill, R.C. Bohlin, & G. Hartig
FOS Instrument Science Report CAL / FOS-077 April 1992

Table 1: FOS observational parameters.

The G190H and G270H FOS spectra must also be corrected for grating scatter. The procedure used for this correction is described in an earlier paper by Cunningham and Caldwell in these proceedings. Finally the spectra are resampled with a triangular binning at 1Å intervals and the spectra from the 2 gratings are combined with an average spectrum being used in the overlapping wavelength region.

All of the FOS observations of the outer planets used identical calibration reference files and tables for the pipeline reductions. There are no anomalous files in the headers for the Saturn observations that would suggest that these data were processed differently by the pipeline. All calibration switches are identical as well.

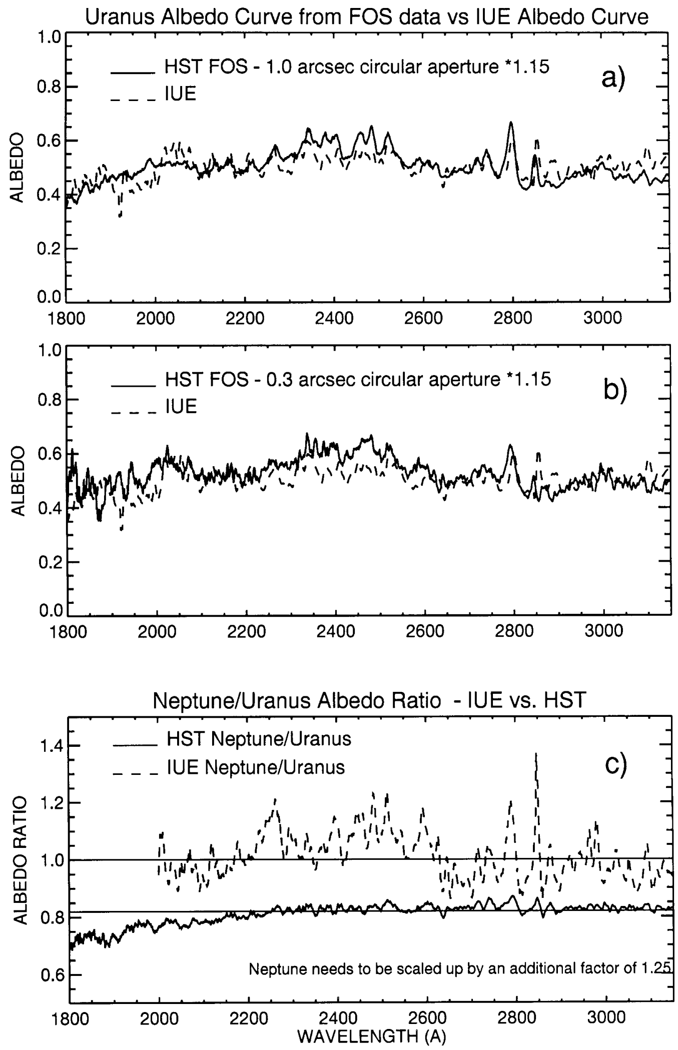

Figure 4: Uranus Albedo curve from FOS data compared to *IUE* albedo measurements.

Processing of the FOS spectra was identical in approach. Different FOS apertures returned identical albedo curves for the Jupiter spectra (1.0 arcsec circular and 0.25 by 2.0 arcsec rectangular apertures) and the Uranus and Neptune spectra (1.0 arcsec and 0.3 arcsec circular apertures). This is well illustrated in Figure 4.

Figure 4a compares the 1.0 arcsec FOS albedo curve derived for Uranus with an earlier whole disk *IUE* albedo measurement. The 15 percent difference could be due to real changes in the albedo curve for Uranus or could be due to limb darkening effects that have been over compensated for in the derivation of the *IUE* albedo curve. Figure 4b is identical to 4a except that the 0.3 arcsec FOS Uranus albedo curve is now compared to the *IUE* data. Figure 4c compares the ratio of the Neptune albedo to the Uranian albedo for *IUE* to the same ratio obtained from FOS 1.0 arcsec aperture measurements of the 2 objects. If the 15 percent difference between the Uranus *IUE* and FOS albedo measurements is assumed to be due to effects other than FOS calibration then Neptune should exhibit a similar difference when the FOS and *IUE* curves are compared. In fact, the difference between the *IUE* and FOS albedo curves for Neptune should be less than in the case of Uranus as Neptune is only about 2.3 arcsecs in diameter and so the FOS measurement is closer to a whole disk average than the FOS Uranus measurement. The *HST* FOS Neptune/Uranus curve should therefore only be about 15 percent different from the *IUE* Neptune/Uranus curve. In reality, however, an additional scaling factor of 1.25 needs to be applied to the *HST* ratio in order to bring it into agreement with the *IUE* ratio.

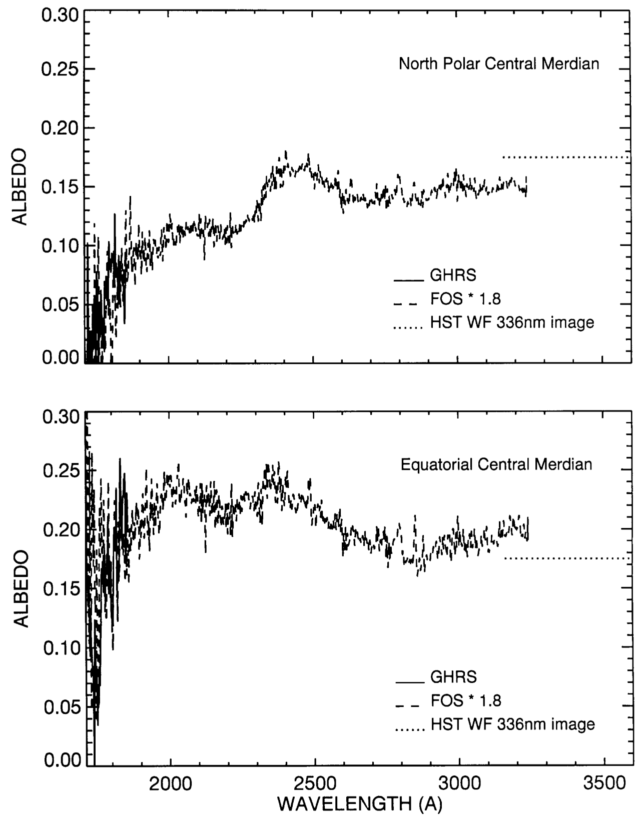

Figure 5: Saturn albedo measurements from FOS, GHRS and WFPC observations obtained in December 1992. It is necessary to scale the FOS observations by 1.8 in order to bring them into agreement with the observations from the other 2 *HST* instruments.

The trend indicated by the Uranus (15 percent change) and Neptune (30 percent change) data is too uncertain to draw any conclusions about whether the differences between the *IUE* and the FOS measurements of these two objects is indicative of a gradual change in the FOS sensitivity.[1] The differences between the *IUE* and the FOS observations of these objects could be explained by real changes in the planetary albedos, combined with small fluctuations in FOS sensitivity.

1. Results from FOS sensitivity monitoring are presented elsewhere in this volume.

The Saturn data set, however, is very difficult to understand. Observations from *IUE* are not required for determining the scaling factor for the FOS Saturn observations as near-simultaneous GHRS and WFPC observations of Saturn were made with the FOS observations. The GHRS observations targeted the equatorial central meridian and the north pole central meridian regions. While the GHRS observations may sample different longitudes than the FOS observations actual longitudinal effects can not account for more than a 10-15 percent difference in the composite FOS and the composite GHRS spectra. The WFPC image of Saturn was calibrated using Saturn's B-ring and independent calibration of the B-ring by Lebofsky and Fegley (1976). A single albedo over the bandpass of the F336W filter is plotted in Figure 5 for both the equatorial central meridian and the north pole central meridian regions. The corresponding FOS observations (scaled by a factor of 1.8) and the GHRS observations are also plotted in Figure 5. The scaling factor of 1.8 brings the FOS observations (G190H and G270H) into reasonable agreement with both the WFPC and GHRS measurements.

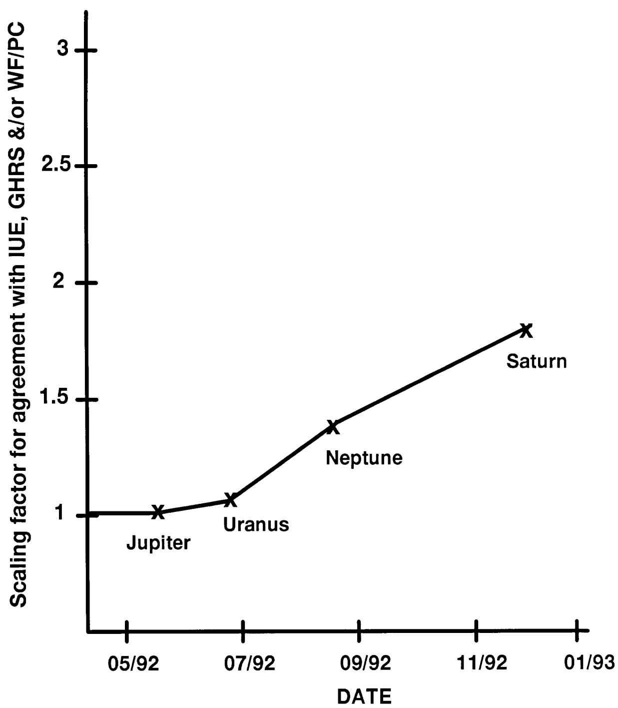

Figure 6: Scaling factors to bring FOS albedo measurements of the giant planets into agreement with GHRS & *IUE* (Jupiter), *IUE* (Uranus & Neptune), and GHRS & WFPC (Saturn) imaging plotted against date of the observation.

If the scaling factors for the four planetary data sets (Jupiter – FOS scaled to GHRS and *IUE*; Uranus FOS – 2 apertures scaled to *IUE*; Neptune 2 apertures scaled to *IUE*; and Saturn – 1 FOS aperture at 3 regions on the disk scaled to GHRS for the same regions, and WFPC imaging) are plotted against time the trend is difficult to miss (Figure 6). The cause for the change in the FOS spectrum with time is not clear.

While it may be possible to explain the Uranus and Neptune observations with real albedo changes combined with small instrument calibration errors the Saturn observations preclude this as a reasonable explanation. This discrepancy between the *HST* FOS observations and the GHRS and WFPC observations is unresolved.

III. Conclusion

The problems with overlapping spectral regions can best be explained by a misalignment in the diodes or the electronic analogue of a physical misalignment. This misalignment is apparent for objects that fill the aperture in both the GHRS and FOS instruments and can cause errors of the order of 10 percent at the ends of any given dataset.

The problem with the FOS spectrum of Saturn remains unresolved. The FOS calibration of stars has not shown a dramatic variation in sensitivity , see this volume.

References

Lebofsky, L. A. and Fegley, M. B. 1976. Laboratory reflection spectra for the determination of chemical composition of icy bodies. Icarus v. 28 p. 379-387.

Neill, J. D., Bohlin, R. C., and Hartig, G. 1992, FOS Instrument Science Report CAL/FOS-077, 16

Van Hoosier, M. E., Bartoe J. F., Bruecker G. E., and Prinz D. K., 1988, Astro. Let. and Commun., 27, 163