POST-COSTAR INTERNAL FOS WAVELENGTH CALIBRATION

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Abstract. The FOS wavelength calibration, last updated late in 1990 by Kriss et al. (CAL/FOS–067), is currently being revised based on data taken after the refurbishment of HST. Starting during the Science Mission Orbital Verfication (SMOV) and continuing through Cycle 4, all in all 10 epochs of internal wavelength calibration measurements were obtained, covering the time range from February 1994 to June 1995. The availability of several measurements for different detector/aperture/disperser combinations will enable us to establish good approximations to the best mean values and to identify outliers. A comparison with the (reprocessed) data by Kriss et al. (1990) will show whether their pre-COSTAR data are still compatible with our new results.

The reduction of the April–August 1994 data indicates that, while the dispersion relations for some of the dispersers might differ noticeably from the old ones by Kriss et al., those of others match the old values so closely that a general change caused by the deployment of COSTAR can be excluded. Deviations appear to be caused by various non-repeatabilities within the instrument and by effects of external magnetic fields on the magnetic deflection in the tubes of the FOS.

The spectra on the red side are – compared with the template spectra from the Calibration Data Base – contracted, i.e., the same lines are found over a narrower range of diodes in the post-COSTAR data. Since this effect is not seen on the blue side, it is probably not caused by the deployment of COSTAR, but rather by an internal change in the red side detector, as, e.g., the high voltage.

After the establishment of the best solutions for the internal FOS wavelength calibration, additional new data will be used to recalculate the internal/external wavelength offset.

Key words: FOS – wavelength calibration

1. Introduction

The internal FOS wavelength calibration has been found to be relatively stable over time. Thus, internal non-repeatabilities in the instrument limit the accuracy of the calibration that can be achieved routinely for both the pipeline reduction for shipment to the PI and later reprocessing of archived observations. Therefore, the standard FOS wavelength calibration has not been updated for a relatively long time, namely since the Science Verification (SV) measurements by Kriss et al. (1990; CAL/FOS–067).

Now, four to five years later, and after the HST refurbishment, we are undertaking a major effort to update the FOS wavelength calibration, both internal and the internal/external offset measurements. In doing so we want to achieve several goals.

1. Improved wavelength calibration of new data in the pipeline reduction system.
2. Improved quality of reference tables for off-line recalibration of all post-COSTAR FOS spectra taken with the newly calibrated instrument configurations.
3. If a comparison with the reprocessed Kriss et al. data should show no systematic effects introduced by COSTAR, one could establish a better calibration database also for pre-COSTAR data.

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4. Following from the above points: impoved quality of HST archive data that are reprocessed using the new reference tables.

In the following we will describe the current status of the ongoing new internal wavelength calibration and give as an example the dispersion relations for one epoch, April 1994, on the red side.

2. Data base and reduction

2.1 Post-COSTAR wavelength calibration measurements

Up to now, data are available for a total of ten epochs, spanning the time range from February 1994 to June 1995, see Table 1. Table 2 lists the detector/disperser/aperture combinations for which calibration data were taken.

TABLE I
Post-COSTAR internal wavelength calibration data

Epoch	Proposal ID	HST Cycle
Feb. 94	4774	SMOV
Apr. 94	5535	4
June 94	5535	4
June 94	5536	4
Aug. 94	5535	4
Oct. 94	5535	4
Dec. 94	5535	4
Feb. 95	5535	4
Apr. 95	5535	4
June 95	5535	4

2.2 Reduction procedure

All data are reduced following exactly the procedure developed by Kriss et al. (1990). This leads to the highest possible degree of compatibility of their results with ours. Note that the Kriss et al. analysis was also compatible with earlier measurements by Sirk & Bohlin (1986). Thus, continuity in the FOS wavelength calibration procedures over time is ensured. The individual reduction steps are described in the following.

We use the calibrated .C5H and .C5D files for the data analysis. Paired-aperture internal spectra are now handled correctly by the Routine Science Data Processing (RSDP) system, so that no reprocessing of these data was necessary. The prism spectra were combined from two exposures each, one short (1 s), the second long (10 s). For the red side, long exposure data were used for pixels 1–1771 in order to increase the signal-to-noise (S/N) compared to the short inegrations. These were used for pixels 1772–2064, because the high signal intensity would otherwise have led to wrap-arounds in the spectra. On the blue side, the transition point is pixel 293, below which short integration time data were used. This leads to good S/N for lines across the entire spectral range, which are needed in order to tie the polynomial fit as closely as possible to the data for all wavelengths, out to the edges of the diode array.

For the cross correlation we use the IRAF/STSDAS task *linefind* (Sirk & Bohlin 1986, Kriss et al. 1990), with the same peak-finding kernel (three-point triangle with relative weights 0.8, 1.0, 0.8) as used by these authors, and the line tables by Kriss et al. (1990) and Kriss et al. (1988).

The polynomial fits were carried out with the task *dispfity*, fitting a third-order polynomial of the form

$$\lambda = A + Bx + Cx^2 + Dx^3$$

to the grating spectra and a fifth-order polynomial of the form

$$\lambda = A_\circ + \frac{A_1}{(x - X_\circ)} + \frac{A_2}{(x - X_\circ)^2} + \frac{A_3}{(x - X_\circ)^3} + \frac{A_4}{(x - X_\circ)^4}$$

to the prism data. As done by Kriss et al. (1990), we weighted the lines in the grating spectra equally. In the prism spectra they were weighted by the reciprocal of the local dispersion in order to preserve the uniformity of errors in diode space.

TABLE II
Calibrated detector/disperser/aperture combinations

FOS/BL				FOS/RD			
Paired Apertures	Disperser Element	Single Aperture	Disperser Element	Paired Apertures	Disperser Element	Single Aperture	Disperser Element
$0''.1$-PAIR	PRISM	$0''.3$	PRISM	$0''.1$-PAIR	G270H	$0''.3$	PRISM
	G270H		G130H		G400H		G190H
	G400H		G190H		G570H		G270H
	G650L		G270H		G780H		G400H
$0''.25$-PAIR	G130H		G400H		G650L		G570H
	G190H		G570H	$0''.25$-PAIR	PRISM		G780H
	G570H		G780H		G190H		G160L
	G160L		G160L		G160L		G650L
			G650L				

3. Preliminary results

3.1 Dispersion relations for April 1994 data

In the Appendix of this paper we show in Table III as an example the dispersion coefficients for the April 1994 on the red side (FOS/RD). Please note that these serve only for comparison with table 2 by Kriss et al. (1990). They are not yet the final values which will be used for the new calibration. These will be median values from all ten available epochs, after exclusion of obvious outliers.

3.2 Systematic changes caused by COSTAR

Compared to the old dispersion coefficients which are currently used for online pipeline data reduction we see no systematic changes in the FOS blue side spectra. The old dispersion coefficients for some of the dispersers reproduce so exactly that currently we have no indication of systematic effects caused by the deployment of COSTAR. On the red side, the spectra are slightly "contracted", i.e., spectra are shorter in diode space than they used to be (by about 0.6 to 0.8 diodes over the whole array of 512 diodes). Since this is not seen on the blue side, the effect cannot have been introduced by COSTAR, but is more probably due to a change in the magnetic deflection, e.g., through a difference in the high-voltage settings. This topic is currently still under investigation.

3.3 Limiting factors to the FOS wavelength calibration

The highest possible accuracy for FOS wavelength calibration can only be achieved via contemporaneous calibration measurements as part of a science proposal leading or following directly the science exposures, without *any* change in the instrument setup. The physical "hard" limit for FOS wavelength calibration is the non-linearity of the diode array, which leads to a minimum achievable inaccuracy of about 0.02 diodes (Sirk & Bohlin 1986). The uncertainties for spectra taken without such accompanying calibration data are much larger and they can depend on different factors. These are:

1. aperture wheel non-repeatability ($\simeq 0.1$ diode)
2. filter-grating wheel non-repeatability ($\simeq 0.15$ diode)
3. residual uncertainties in the magnetic deflection after correction for the geomagnetically-induced image motion (GIM).

The typical non-repeatability of the FOS wavelength scale under these circumstances is about 0.35 diodes.

4. Current status and future work

At present, data from three out of ten epochs have been evaluated. The reduction of the remaining data is underway. Re-reduction of the data by Kriss et al. (1990), which—at the time when they were reduced—were not GIM-corrected, will lead to information on the influence of GIM on their data, because now—when retrieved from the public HST data archive—the GIM correction has a posteriori been applied. This step is important for several reasons. It will allow an unbiased comparison of the old and new data and thereby enable us to judge the effects of COSTAR on the internal wavelength calibration. If the solutions for the pre-COSTAR and post-COSTAR eras are compatible, we can determine a new improved wavelength calibration scale for FOS data taken pre-COSTAR, which would lead to an improvement of the off-line re-reduction of data taken from the archive.

New reference tables will be delivered to the Calibration Data Base System (CDBS), leading to improved pipeline data calibration. The final results of this analysis will be published in an instrument science report, which will be available through the World Wide Web pages maintained at STScI.

Monitoring of the internal FOS wavelength calibration will continue through Cycle 5 in bi-monthly intervals (proposal ID 6236), adding more data to the ten currently available epochs.

Combination of the new internal calibration with new internal/external offset measurements (proposal ID 5536) will lead to an improved external FOS wavelength calibration. This will be the subject of another instrument science report.

5. Acknowledgements

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6. References

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Kriss, G. A., Blair, W. P., & Davidsen, A. F. 1990, CAL/FOS–067, “In-Flight FOS Wavelength Calibration - Template Spectra”

Sirk, M. & Bohlin, R. 1986, CAL/FOS–026, “FOS Wavelength Calibration”

7. Appendix: Example of the newly measured dispersion coefficients

TABLE III

Dispersion coefficients for April 1994 measurements FOS/RD

DET	DISP	APERTURE	COEFF1	COEFF2	COEFF3	COEFF4	COEFF5	COEFF6	RMS (DIODES)
RED	G650L	0.1-PAIR-L	8731.40	-24.880820	2.365238E-03	-4.488705E-06	0.000000E+00	0.000000E+00	0.034
RED	G650L	0.1-PAIR-U	8732.73	-24.882740	2.051896E-03	-3.679774E-06	0.000000E+00	0.000000E+00	0.030
RED	G780H	0.1-PAIR-L	9224.37	-5.738585	1.227887E-04	-1.833832E-07	0.000000E+00	0.000000E+00	0.031
RED	G780H	0.1-PAIR-U	9225.45	-5.742429	1.158972E-04	-1.641117E-07	0.000000E+00	0.000000E+00	0.025
RED	G270H	0.1-PAIR-L	3278.12	-2.046582	2.827383E-05	-5.352665E-08	0.000000E+00	0.000000E+00	0.037
RED	G270H	0.1-PAIR-U	3278.18	-2.046350	2.463332E-05	-4.725305E-08	0.000000E+00	0.000000E+00	0.032
RED	G570H	0.1-PAIR-L	6821.60	-4.358392	4.440152E-05	-9.499911E-08	0.000000E+00	0.000000E+00	0.034
RED	G570H	0.1-PAIR-U	6821.71	-4.361379	6.339360E-05	-1.255878E-07	0.000000E+00	0.000000E+00	0.034
RED	G400H	0.1-PAIR-L	4784.41	-2.994085	2.072025E-05	-5.449032E-08	0.000000E+00	0.000000E+00	0.034
RED	G400H	0.1-PAIR-U	4784.45	-2.995122	2.723539E-05	-6.501985E-08	0.000000E+00	0.000000E+00	0.041
RED	G150L	0.25-PAIR-L	2427.24	-6.946583	2.130865E-03	-1.211635E-05	0.000000E+00	0.000000E+00	0.036
RED	G150L	0.25-PAIR-U	2427.27	-6.905989	1.267531E-03	-7.065193E-06	0.000000E+00	0.000000E+00	0.037
RED	PRISM	0.25-PAIR-L	1150.75	-136121.721845	-1.865602E+06	-3.625468E+07	-2.315725E+08	5.092572E+02	0.115
RED	PRISM	0.25-PAIR-U	1167.78	-131519.559378	-1.651835E+06	-2.669583E+07	-1.507366E+08	5.077859E+02	0.149
RED	G190H	0.25-PAIR-L	2312.37	-1.430986	-7.516000E-07	-1.080392E-08	0.000000E+00	0.000000E+00	0.021
RED	G190H	0.25-PAIR-U	2312.60	-1.433547	8.133773E-06	-2.030012E-08	0.000000E+00	0.000000E+00	0.029
RED	G400H	0.3	4783.79	-2.995047	2.646293E-05	-6.313948E-08	0.000000E+00	0.000000E+00	0.035
RED	G650L	0.3	8722.46	-24.816947	1.556108E-03	-2.663710E-06	0.000000E+00	0.000000E+00	0.033
RED	G780H	0.3	9219.87	-5.706013	1.664506E-05	-7.696140E-08	0.000000E+00	0.000000E+00	0.046
RED	G270H	0.3	3277.90	-2.045560	2.388531E-05	-4.751895E-08	0.000000E+00	0.000000E+00	0.034
RED	G570H	0.3	6820.31	-4.359169	5.472177E-05	-1.080420E-07	0.000000E+00	0.000000E+00	0.036
RED	G150L	0.3	2428.67	-7.069826	4.558348E-03	-2.648293E-05	0.000000E+00	0.000000E+00	0.042
RED	PRISM	0.3	1155.49	-134591.589840	-1.809077E+06	-3.221175E+07	-1.945499E+08	5.083283E+02	0.102
RED	G190H	0.3	2312.18	-1.433987	1.156234E-05	-2.692545E-08	0.000000E+00	0.000000E+00	0.033