Recalibrating Pre-COSTAR FOS Data

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Abstract

A description of the methods by which pre-COSTAR non-polarimetric FOS data may be recalibrated using the photometric corrections and calibrations of Lindler and Bohlin (1994) is presented. Recalibration is accomplished through the use of the IRAF/STSDAS task `calfos` (version 2.0), which includes corrections for deviations in OTA focus, changes in sensitivity over time, and new inverse sensitivity data based on the switch from the IUE absolute flux scale in the UV to a model atmosphere flux distribution for G191B2B.

I. Introduction

Lindler and Bohlin (1994; LB94) have rederived the pre-COSTAR absolute photometric calibration for the Faint Object Spectrograph non-polarimetric observing modes, superceding the calibrations of Neill, Bohlin, and Hartig (1992; NBH) which were used in the routine pipeline processing of cycle 1-3 FOS data. The fundamental differences in the NBH calibration and the superceding work of LB94 are the corrections for changing instrumental sensitivity over time, the correction for the deviation of OTA focus from the baseline, and the switch from the IUE flux scale in the UV to a scale defined by a pure hydrogren model atmosphere flux distribution for the standard star G191B2B (see LB94 for details).

The LB94 calibrations approach an internal photometric precision of 1% in the high dispersion gratings, which implies a photometric accuracy for an individual stellar observation that is limited by the photon statistics, pointing accuracy, OTA breathing, and aperture size for the particular spectrum. Thus, the accuracy of absolute fluxes measured in any FOS science observation will be limited by the uncertainties in the observation itself, rather than by any deficiencies in the calibration algorithm.

Note that post-COSTAR FOS data (as of this writing) processed at STScI with the standard pipeline still utilize the older flux calibrations methods, however the basis for the post-COSTAR flux scale has been switched to the white dwarf model atmosphere system. As soon as appropriate post-COSTAR focus correction and sensitivity degradation information becomes available, the pipeline system will be upgraded to include these corrections.

Pre-COSTAR non-polarimetric FOS data can be reprocessed to take advantage of the LB94 calibration using the task `calfos` in the `hst_calib.fos` package of STSDAS. The

LB94 calibrations are only available in versions 2.0 and higher of the `calfos` task. If you have an earlier version you can obtain a more recent one from STScI by contacting the STSDAS support HotSeat by phone at 410-516-5100 or by e-mail to *hotseat@stsci.edu*.

Section 2 of this report describes the new calibration methods and how they differ from the previous flux calibration method. Section 3 contains instructions for preparing and reprocessing existing FOS data using the new calibration methods.

II. The New Flux Calibration Methods

FOS data that were processed with `calfos` using the NBH calibrations were converted from observed count rates to absolute fluxes by simply multiplying by the inverse sensitivity (IVS) curve that was appropriate for the particular combination of detector, disperser, and aperture used in the observation. The appropriate IVS data were selected by setting the values of the `IV1HFILE` and `IV2HFILE` header keywords in the raw science data image (the ".d0h" file) to the names of the reference files that contained the necessary IVS data. Non-polarimetric data obtained through a single aperture used a single IVS file, specified by the `IV1HFILE` keyword. Data obtained through paired apertures used two IVS files, one for each aperture position, specified by the `IV1HFILE` and `IV2HFILE` keywords.

The LB94 calibrations, on the other hand, utilize a single IVS curve for each detector and disperser combination that is derived from standard star observations obtained with the 4.3 arcsecond square (A-1) aperture. Data obtained through all entrance apertures—for a given detector/disperser combination—use this one IVS curve to convert count rates to absolute fluxes, but also undergo an additional correction that accounts for the differences in aperture throughputs relative to the A-1. Under this new scheme paired aperture observations also use a single IVS curve for calibration. Any differences between the lower and upper apertures of the pair are accounted for in the aperture throughput correction step.

The processing flow within `calfos` is as follows. All processing steps up to the point of the existing flux calibration—including count to countrate conversion, GIMP correction (if necessary), paired-pulse correction, background subtraction, scattered light subtraction, flat fielding, and wavelength calculation—remain the same as before. The first of the new calibration steps is the correction for aperture throughput relative to the A-1 aperture. This processing step is controlled by the new raw image header keyword `APR_CORR` and uses a new calibration reference table specified by the raw image header keyword `CCSB`. The `CCSB` table contains polynomial coefficients describing the throughput as a function of wavelength for each aperture relative to the A-1 aperture. For paired apertures there is a separate set of throughput coefficients for the upper and lower apertures. The spectral data are corrected by dividing the net count rates by the polynomial derived from the `CCSB` table coefficients.

The `APR_CORR` step also includes the correction for changes in aperture throughput as a function of OTA focus. The focus history of the OTA is stored in a calibration reference table specified by the new header keyword `CCSA`. The `CCSA` table contains the deviation (in microns) from the nominal focus position, which is the focus setting of the OTA on 18 October 1991, as a function of Modified Julian Date (MJD). Relative aperture throughputs as a function of OTA focus are contained in the reference table specified by the new CCSC header keyword. This table contains values of throughput relative to the throughput at nominal focus as a function of wavelength and focus for each detector and aperture combination. The correction is applied by linearly interpolating within the CCSA table data to determine the focus position corresponding to the date of the observation, and then using bi-linear interpolation within the CCSC table data to determine the relative throughput for the focus position and wavelength of each spectral data point. Each data point is then divided by the relative throughput value.

The next step in the new calibration process is the application of the IVS curve to convert the data from units of countrates to absolute fluxes. In order to avoid confusion with the IVS reference files used by the old process the LB94 IVS reference files are specified by the new header keyword AISHFILE (Average Inverse Sensitivity Header FILE) and, similarly, the switch controlling this step has been given the new header keyword name AIS_CORR (the old process is controlled by the FLX_CORR keyword). Furthermore, the new AIS reference files use a file name extension of ".r8h", instead of the the ".r2h" extension used by the old IVS files.

The final step in the new calibration process is the correction of the absolute fluxes for changes in instrumental sensitivity over time. This step is controlled by the new header keyword TIM_CORR and uses a reference table specified by the new keyword CCSD. The CCSD table contains correction factors as a function of wavelength and MJD for each detector/disperser combination. Corrections for each spectral data point are determined by using bi-linear interpolation to determine the appropriate correction for the date of the observation and the wavelength of the data point.

III. Recalibrating Your Data

In order to recalibrate your (non-polarimetric) pre-COSTAR FOS datasets it is necessary to first add the eight new keywords to your raw image header files. A summary of the required new keywords is given in Table 1. Table 1 also includes the names of the relevant reference tables that you must have in order to apply the new flux calibration steps. The four reference tables—CCSA, CCSB, CCSC, and CCSD—contain information for all detector/disperser/aperture combinations and therefore only one of each type of table is required to process any observation. There are fourteen different AIS reference files; one for each supported detector/disperser combination. A complete list of the AIS reference files is given in Table 2.

The keywords and their values may be added to the raw image headers individually using, for example, the IRAF task `hedit`, or they can all be added at once using the special task `addnewkeys` which is available in the STSDAS package `hst_calib.fos`. The `addnewkeys` task will read the values of the `detector` and `fgwa_id` keywords in the raw data files and automatically select the appropriate file for the AISHFILE keyword.

If you do not have the reference tables or files on your computer system, you can obtain them via anonymous ftp from STScI on node *ftp.stsci.edu*. See the Appendix for step-by-step instructions on obtaining and installing the files.

Now all that is left to do is to reprocess the raw datasets using the `calfos` program. Note that `calfos` versions 2.0 and higher are backwards compatible with the old flux calibration methods, *i. e.* you can process datasets that do not contain the new header keywords or you can set the APR_CORR, AIS_CORR, and TIM_CORR keywords to "OMIT" and set the FLX_CORR keyword to "PERFORM", in which case the old flux calibration method will be applied to the data. The software will not allow *both* methods to be applied to any one dataset. If any one of the APR_CORR, AIS_CORR, or TIM_CORR keywords is set to "PERFORM", they will take precedence and FLX_CORR will automatically be skipped.

Furthermore, the APR_CORR (aperture correction) step is a prerequisite for the AIS_CORR (flux calibration) step because the countrate data must first be scaled to the throughput of the AIS reference aperture (usually the A-1) before the inverse sensitivity function can be applied. Therefore both APR_CORR and AIS_CORR must be set to "PERFORM" in order to obtain an accurate absolute calibration. If either one is set to "OMIT", the other will also be omitted by `calfos`.

The following is a sample of the processing log that will be printed by `calfos` when applying the new flux calibration methods to a dataset. Messages from the early (unchanged) processing steps have been omitted for brevity.

```
*** CALFOS - Version 2.0 : STSDAS - Version 1.3.2 ***
Y0AN0504T  Begin CALFOS for input file rootname: y0an0504t
Y0AN0504T                 output file rootname: y0an0504t
Y0AN0504T  Data quality initialization done using ...
Y0AN0504T  ...
Y0AN0504T  Aperture throughput coefficients from ytab$e9f1430ny.cyb
Y0AN0504T    LOWER aperture:
Y0AN0504T    wmin =  1588.0  wmax =  2317.0
Y0AN0504T    c0 =  0.544160E-01  c1 =  0.201469E-03  c2 = -0.383119E-07
Y0AN0504T    UPPER aperture:
Y0AN0504T    wmin =  1588.0  wmax =  2317.0
Y0AN0504T    c0 =  0.544160E-01  c1 =  0.201469E-03  c2 = -0.383119E-07
Y0AN0504T  Focus history from ytab$e8c13579y.cya
Y0AN0504T    Focus error for MJD 48122.382 =  -2.8549     microns
Y0AN0504T  Focus corrections from ytab$e8c13588y.cyc
Y0AN0504T    Mean aperture throughput focus correction =  0.99078
Y0AN0504T  Conversion to abs. flux units using yref$e9f1319my.r8h
Y0AN0504T  Sensitivity time corrections from ytab$e8c1357ky.cyd
Y0AN0504T  Reference file PEDIGREE information:
Y0AN0504T  AISHFILE=yref$e9f1319my.r8h       AIS_CORR=COMPLETE
Y0AN0504T  INFLIGHT
Y0AN0504T  Average Pre-Costar A-1 inverse sensitivity
Y0AN0504T  Reduction completed for input file y0an0504t
```

This is a paired aperture observation, therefore there are two sets of aperture throughput coefficients (although in this case they are identical). The three coefficients describe the second-order polynomial function that is applied to the countrate data to place it on an absolute scale equivalent to the A-1 aperture. The relative throughput for some apertures is defined by separate functions over different portions of the wavelength range of the grating. The renormalized countrate data have also been corrected for a change in OTA focus of about 3 microns from the nominal position. The countrate data have then been converted to absolute flux units using the average inverse sensitivity curve in reference file e9f1319my.r8h and also corrected for changes in instrumental sensitivity appropriate for the date of the observation using information from the reference table e8c1357ky.cyd.

References

Lindler, D. J., and Bohlin, R. C. 1994, FOS Instrument Science Report CAL/FOS-125 (LB94).

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

Appendix

The FOS calibration reference files and tables can be retrieved via anonymous ftp from node *ftp.stsci.edu* (IP address 130.167.1.125). The reference tables are located in directory `/cdbs/ytab` and the reference files are in directory `/cdbs/yref`. The tables and files are stored on this node in Sun binary format. Therefore if your host computer is a VAX/VMS system you will need to convert the files after you have retrieved them. Use the STSDAS tasks `tconvert` to convert tables and `sun2vax` to convert images. After you have retrieved and converted the files, place them in the directories on your system that are referenced by the STSDAS "`ytab`" and "`yref`" environment variables.

The exact steps for retrieval are as follows:

1)	`ftp ftp.stsci.edu`	(to connect to stsci)
2)	`anonymous`	(login as anonymous)
3)	*your e-mail address*	(just for information)
4)	`bin`	(set transfer mode to binary)
5)	`cd /cdbs/ytab`	(change to the tables directory)
6)	`get e8c13579y.cya`	(get a table)
7)	`cd /cdbs/yref`	(change to the images directory)
8)	`get e9f13201y.r8h`	(get an AIS image)
9)	`bye`	(to exit from ftp)

Table 1
New Header Keywords

Keyword	Default Value	Function
APR_CORR	PERFORM	Aperture throughput correction switch
AIS_CORR	PERFORM	Flux calibration switch
TIM_CORR	PERFORM	Time change in sensitivity switch
CCSA	ytab$e8c13579y.cya	CCSA reference table name
CCSB	ytab$e9f1430ny.cyb	CCSB reference table name
CCSC	ytab$e8c13588y.cyc	CCSC reference table name
CCSD	ytab$e8c1357ky.cyd	CCSD reference table name
AISHFILE	(see Table 2)	AIS reference file name

Table 2
AIS Reference Files

Detector	Disperser	AISHFILE	Detector	Disperser	AISHFILE
AMBER	H13	(not supported)	BLUE	H13	yref$e9f13201y.r8h
AMBER	H19	yref$e9f1319my.r8h	BLUE	H19	yref$e9f13202y.r8h
AMBER	H27	yref$e9f1319ny.r8h	BLUE	H27	yref$e9f13203y.r8h
AMBER	H40	yref$e9f1319oy.r8h	BLUE	H40	yref$e9f13204y.r8h
AMBER	H57	yref$e9f1319qy.r8h	BLUE	H57	(not supported)
AMBER	H78	yref$e9f1319ry.r8h	BLUE	H78	(not supported)
AMBER	L15	yref$e9f1319sy.r8h	BLUE	L15	yref$e9f13205y.r8h
AMBER	L65	yref$e9f1319ty.r8h	BLUE	L65	(not supported)
AMBER	PRI	yref$e9f13200y.r8h	BLUE	PRI	yref$e9f13206y.r8h