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The Next Step for the FUSE Calibration Pipeline

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Abstract. The calibration pipeline for the Far Ultraviolet Spectroscopic Explorer (FUSE) satellite was designed years before it was launched. Since then, a number of unexpected instrumental features were discovered and the pipeline was modified appropriately. Eventually, these changes made the design so cumbersome that the pipeline became difficult to maintain. In 2002, we began to develop a new pipeline concept that takes into account the actual instrument characteristics. We present our plans for this improved calibration pipeline.

1. Introduction

The design of the CalFUSE pipeline dates to well before the launch of FUSE. As the primary FUSE mission draws to a close and an extended mission begins, the resources available for maintaining the existing pipeline will diminish. Thus, it is prudent to rethink the design, consider ways to make it easier to maintain, and investigate changes which may improve the data quality. This process was begun in the summer of 2002 when we proposed that for version 3 of the pipeline, a new method for calibrating the data be used. These changes, which are described in the following sections, are intended to improve the data quality while ensuring flexibility for future modifications. The ideas for these changes have been prompted by our three years of experience with FUSE data, along with information obtained during the design of the pipeline for the Cosmic Origins Spectrograph, which will use a similar detector (Beland et al., this conference).

The present FUSE pipeline (Dixon et al. 2003) is less flexible than desired when dealing with a number of instrument properties which were discovered (or appreciated more clearly) after launch. These include the thermally-induced motions of the mirrors and gratings, changes in the detector y scale as a function of count rate, event bursts, the "worm," and the decrease in pointing stability due to the failure of reaction wheels. Some of these effects are due to unexpected performance of the instrument hardware, while others are a consequence of the analog nature of the double delay line detectors. Among the shortcomings of the original design are the fact that time-tag data was converted into a two-dimensional image in an early step. Although this would work well if there were no time-varying effects on the data, this is not the case for FUSE.

In addition to being developed with the instrument anomalies in mind, the new design is more flexible, so that any new effects discovered as the instrument

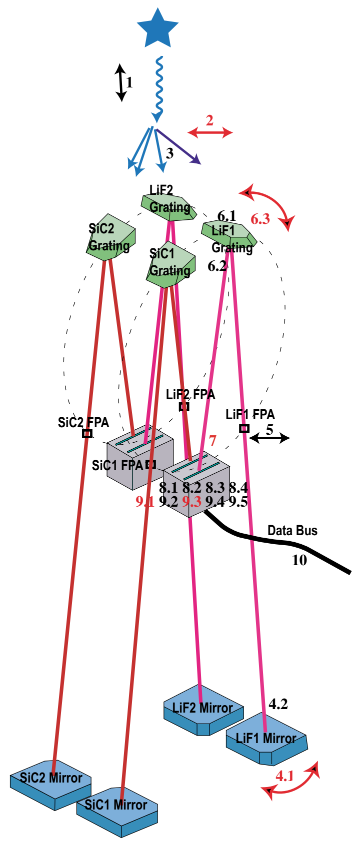

Figure 1. A schematic view of the path of a photon through the FUSE instrument. The steps which affect the data (and consequently, the pipeline) are numbered; each of these must be compensated for in the pipeline process.

ages can be dealt with more gracefully. The modular design should allow for the addition of new modules with little or no effects on the existing ones. Although the current design also permitted modules to be added, the fact that each created its own output file and expected a unique format for its input made this difficult.

2. The Life and Death of a Photon

Figure 1 shows the path of a photon through the instrument. This list describes each effect. Items marked with an asterisk were not considered in the original pipeline design.

1.1 Doppler Shift due to motion of satellite.
1.2 Wavelength shift due to heliocentric motion.
2. *Satellite pointing jitter.
3. Four Barrel design — divides incoming light among channels.

4.1 *Mirror motions due to thermal effects, which cause motion of the spots at the FPAs.
4.2 Mirror reflectivity.
5. Focal Plane Assembly (FPA) position, which shifts the location of the spectra on the detectors.
6.1 Grating efficiency.
6.2 Dispersion & astigmatism due to grating design & alignment.
6.3 *Grating motions due to thermal effects, which cause motion of the spectra on the detector.
7. *The "worm," caused by an interaction of the optical design and the detector grid wires.
8.1 Detector quantum efficiency.
8.2 Detector flat field.
8.3 Detector bad pixels.
8.4 Detector background.
9.1 *Detector "walk" — position of photon depends on pulse height.
9.2 Detector geometric distortion effects.
9.3 *Detector change in Y scale as a function of count rate.
9.4 Detector shift and stretch as a function of temperature.
9.5 Detector electronics dead time.
10. Instrument Data System (IDS) computer dead time.

3. Processing Steps

A major improvement in version 3 is the use of a single Intermediate Data File (IDF) for the entire pipeline. The IDF is a FITS file containing a binary table in the first extension. This extension contains one row per photon, and has columns for time, x, y, and pulse height from the raw data; x and y in the geometrically undistorted detector frame; a weighting factor for each photon; x and y after all motions are removed; channel; and wavelength. Nearly all of the pipeline modules operate on this one file, by reading and writing particular columns. A simplified outline of the processing steps is presented below. The numbers in parentheses refer to the steps in the previous section.

Put all photons in a rectified image frame:

- Adjust photon weight for IDS dead time (10).
- Adjust photon weight for detector electronics dead time (9.5).
- Correct (x,y) position of photon for thermal stretch & shift (9.4).
- Adjust y position of photon based on count rate (9.3).
- Correct (x,y) position of photon for geometric distortion (9.2).
- Adjust x position of photons to account for detector "walk" (9.1).

Remove Motions:

- Identify channel (LiF1, SiC1, etc.) for each photon.
- Calculate the time-dependent y centroid for each aperture.
- Adjust (x,y) position of photons to correct for grating motions (6.3).
- Adjust x position of photons to compensate for FPA offsets (5)

- Adjust (x,y) position of photons to correct for mirror motions (4.1).
- Use satellite jitter to discard data during particular times (2).
- Calculate the y centroid for all photons in each aperture.

Assign Wavelengths:

- Assign a wavelength to each photon based on position & channel (6.2).
- Correct for the heliocentric motion (1.2).
- Correct for the Doppler shift (1.1).

Screen the Data:

- Identify times when limb angle constraints are violated, or the satellite is in the SAA.
- Identify times when the detector high voltage values are outside of their nominal ranges.
- Find times when event bursts occurred.
- Exclude events which have pulse heights outside the nominal range.

Calibration:

- Convert each photon weight into units of erg cm^{-2} (4.2, 6.1, 8.1)
- Extract a one dimensional spectrum as a function of wavelength for each channel; correct for detector background and flat field (8.2, 8.4).
- Correct for the worm (7).

4. Some Advantages of Version 3

The single Intermediate Data File means that the I/O is the same for all pipeline modules, and thus the order of modules can be changed, or new ones added, with a minimum of complication. The fact that the flow of the pipeline processing steps more closely follows the inverse of the "life of the photon" than previous version did makes it easier for users to understand the steps, and makes it easier to maintain.

Housekeeping (pointing stability, count rates, and high voltage values) data are used where appropriate to improve the quality of the data.

Since every pixel is assigned a floating point wavelength — rather than having every photon put in a wavelength bin as happens now — the final 1-dimensional spectrum can be binned to any convenient wavelength scale. This permits a straightforward addition of data from multiple segments. Because the analog photon positions (with times attached) are maintained for as long as possible, roundoff problems that currently exist will be minimized.

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References

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