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CalFUSE v2.2: An Improved Data Calibration Pipeline for the Far Ultraviolet Spectroscopic Explorer (FUSE)

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Abstract. CalFUSE is the data-reduction software pipeline used at the Johns Hopkins University to process data from the *Far Ultraviolet Spectroscopic Explorer (FUSE)*. The pipeline corrects for a variety of instrumental effects, extracts target spectra, and applies wavelength and flux calibrations. We present improvements included in v2.2 of the pipeline and announce the availability of calibrated spectral files processed with CalFUSE v2.2 from the Multimission Archive at STScI (MAST).

1. Introduction

CalFUSE is the data-reduction software pipeline used at the Johns Hopkins University (JHU) to process data from *FUSE*, the Far Ultraviolet Spectroscopic Explorer. CalFUSE corrects for a variety of instrumental effects, extracts target spectra, and applies wavelength and flux calibrations. Once processed at JHU, both the raw and calibrated data files are shipped to the Multimission Archive at STScI (MAST) for distribution to observers. For the past two years, *FUSE* data have been processed with CalFUSE v1.8.7. In the mean time, the pipeline has undergone considerable development. CalFUSE v2.2, recently released, incorporates more than a dozen major improvements over v1.8.7. We are happy to announce that all new *FUSE* data are now being processed with v2.2. We have begun to reprocess archival *FUSE* data and expect that, by April of 2003, all *FUSE* data in the MAST archive will have been processed with the newest version of CalFUSE.

2. New in CalFUSE v2.2

2.1. Detection and Removal of Event Bursts

Occasionally, the *FUSE* detectors register large count rates for short periods of time. These event bursts can occur on one or more detectors and often have a complex structure, including scalloping and sharp edges (Figure 1). CalFUSE v2.2 includes a module that screens the data to identify and exclude bursts. The data are binned, then median filtered to reject time intervals whose count rates differ by more than N (user-adjustable) standard deviations from the mean. The algorithm also rejects time intervals in which there is no data or in which the

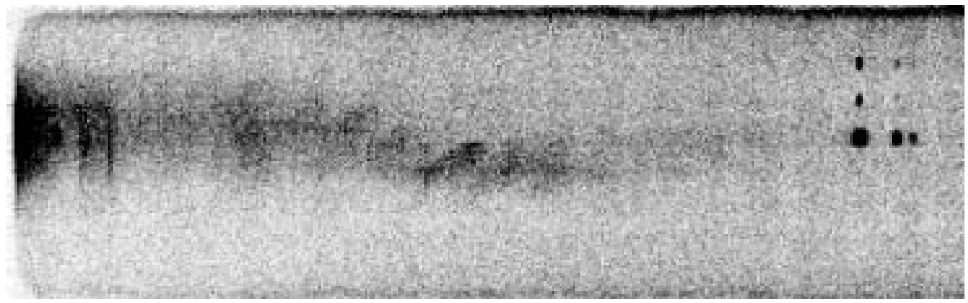

Figure 1. An event burst on the LiF 1 detector.

background rate rises rapidly, as when an observation extends into an SAA. Burst removal is possible only for data obtained in time-tag (TTAG) mode.

2.2. Walk Correction for Low-pulse-height Events

The *FUSE* detectors convert each ultraviolet photon into a shower of electrons, for which the detector electronics calculate the X and Y coordinates and the charge, or pulse height. Prolonged exposure to photons causes the detectors to become less efficient at this conversion (a phenomenon called "gain sag"), and the mean pulse height slowly decreases. Unfortunately, the X coordinate of low-pulse-height photon events is systematically miscalculated by the detector electronics. As the number of low-pulse-height events increases, spectral features appear to "walk" across the detector. The strength of this effect varies with location on the detector, peaking near the Lyman β airglow line at 1026 Å (Figure 2), where the detectors have received the greatest exposure. CalFUSE v2.2 incorporates a module to reposition low-pulse-height events, correcting for this effect. Histogram data, for which pulse-height information is unavailable, are only partially corrected for walk.

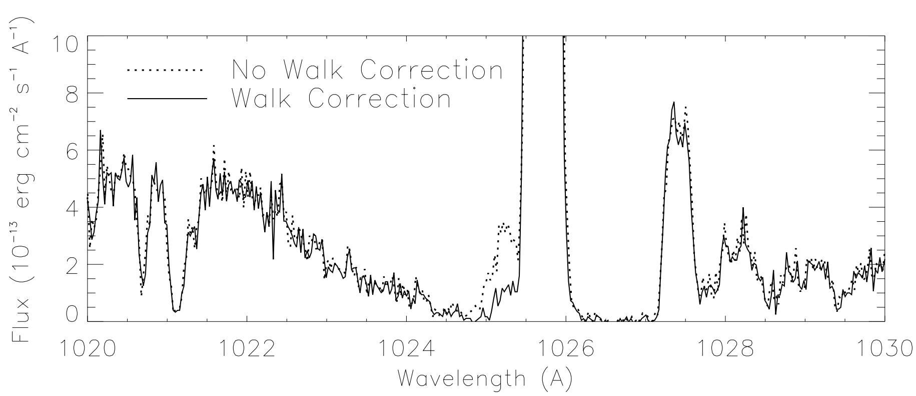

Figure 2. LiF 1A spectrum before and after walk correction.

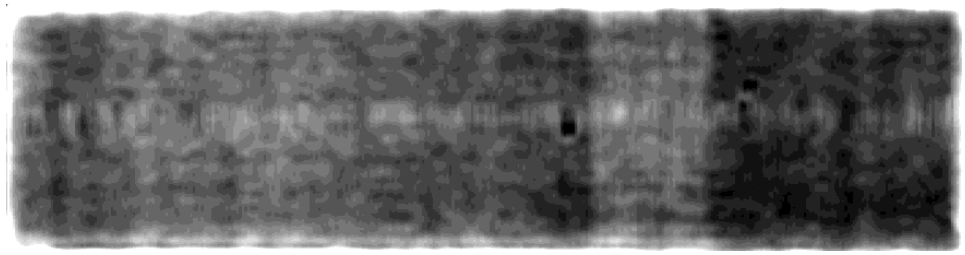

Figure 3. Night-time scattered-light model for detector 1A.

2.3. Jitter-correction Module

We can now correct *FUSE* data for slow drifts resulting from a loss of pointing control during an observation. For time-tagged data, we reposition individual photon events to correct for spacecraft motion. For histogram data, we determine when the target was out of the (LiF 1) aperture and scale the flux accordingly. Both routines use information from a new file, *jitrf.fit, created by OPUS from spacecraft engineering data during level-zero processing. Because this file does not exist for any data processed before August 2002, the jitter-correction routines cannot be applied to older data sets. The incorporation of engineering data into the calibration pipeline is an innovation of CalFUSE v2.2.

2.4. Bad-pixel Maps Reflect Changes in Detector Y Scale

The detector Y scale is not constant, but changes both with time through the mission and as a function of detector count rate. As the Y scale changes, dead spots on the detector move relative to our bad-pixel maps, preventing the pipeline from properly excluding them during spectral extraction. To account for these effects, we have developed a series of bad-pixel maps that span the entire mission, reflecting the change in Y scale with time. Before being applied to the data, the bad-pixel maps are stretched in Y to account for the count-rate-dependent change in the detector Y scale.

2.5. Improved Scattered-light Model

The background has two components, detector dark count and scattered light. The dark count is spatially uniform but varies in intensity with time. The scattered light has considerable spatial structure (Figure 3) and differs between day and night-time observations. CalFUSE v1.8.7 assumes a constant background intensity across the detector. CalFUSE v2.2 scales separate day- and night-time scattered-light images and combines them with a uniform dark-count component to produce a model of the scattered light for each exposure.

2.6. Astigmatism Correction

The astigmatic height of *FUSE* spectra perpendicular to the dispersion direction is significant and varies as a function of wavelength. Moreover, spectral absorption features show considerable curvature, especially near the ends of the detectors, where the astigmatism is greatest. CalFUSE v2.2 shifts the data to correct for the spectral-line curvature introduced by the *FUSE* optics, providing

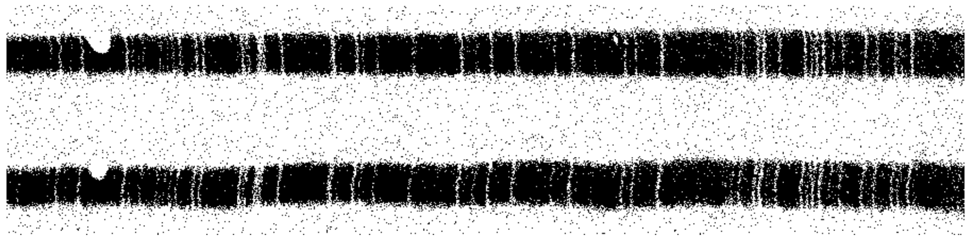

Figure 4. Segment of LiF 1A spectrum before *(bottom)* and after *(top)* astigmatism correction.

a noticeable improvement in spectral resolution for point sources (Figure 4). At present, no astigmatism correction is defined for diffuse sources, and none is applied.

2.7. Optimal (Weighted) Spectral Extraction

The extraction algorithms used in CalFUSE v2.2 provide two important improvements over v1.8.7. First, the software determines the Y coordinate of the target spectrum by performing a cross-correlation between the data (in the form of a detector image) and the known distribution of flux on the detector. This routine greatly improves our ability to center the extraction window on the target spectrum. Second, spectra are extracted via an optimal-extraction algorithm, which produces a weighted sum of the pixels falling within the extraction window. Pixels having a quality flag of BAD_PIXEL do not contribute to the sum. The variances are weighted and summed to produce an error array. Optimal extraction improves the signal-to-noise ratio of the spectra of faint point sources.

2.8. Improved Flux Calibration

CalFUSE v1.8.7 used a single flux-calibration curve for all three apertures, scaling the effective area by the expected throughput of each. CalFUSE v2.2 uses flux-calibration curves for each aperture derived from spectra obtained through that aperture. Since the middle of 2001, we have noticed a slow degradation in the effective area of the *FUSE* spectrograph, more or less independent of wavelength. The flux-calibration files used by CalFUSE v2.2 account for this effect.

3. Conclusions

Now that *FUSE* data processed with CalFUSE v2.2 are available from MAST, we expect that fewer users will find it necessary to download and run CalFUSE at their home institutions. This advance should make *FUSE* data easier to use than ever before.

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