

# Recent Improvements to COS Calibration Pipeline

Philip E. Hodge, STScI

## Abstract:

The pipeline calibration program (`calcos`) for the Cosmic Origins Spectrograph (COS) was originally written based on requirements established in 2002. While the basic outline remains the same, much has been learned about the instrument since then, and extensive testing of `calcos` has helped reveal shortcomings (aka bugs). This paper describes some of the more significant changes, such as for wavelength calibration, keywords for the world coordinate system, and improving the data quality flags.

## Introduction:

COS is an ultraviolet spectrograph designed for very high sensitivity. Both the far ultraviolet (FUV) and near ultraviolet (NUV) channels use microchannel plate detectors, but with very different designs. The FUV channel has two 16k x 1k detectors (“segments”) mounted end to end, and the spectrum runs along both. The NUV channel has a 1k x 1k MAMA detector, and three camera mirrors focus separate portions of the spectrum onto nearby regions of the detector. The preferred operating mode is TIME-TAG, i.e. the raw data file is a table of the arrival times and positions of detected photons. The output products include a corrected TIME-TAG events list (the `corrtag` file), detector images created by binning the `corrtag` table over pixels (`flt` and `counts`), and 1-D extracted spectra (`x1d`).

## WCS Keywords for Spectroscopic Data:

Wavelengths for the 1-D extracted spectra are computed from polynomial expressions developed by the COS instrument team. These wavelengths do not depend on header keywords. World coordinate system keywords are written to images (`flt` and `counts` files) and to corrected TIME-TAG data (`corrtag` files) to make these files more useful to observers.

The COS aperture is 2.5 arcseconds in diameter, which is large compared with a stellar PSF. If the target has resolved spatial structure, each point in the spectrum will have three relevant coordinates: wavelength, right ascension, and declination. Since the detector image is only 2-D, there is an inherent ambiguity in a mapping from pixel coordinates to these world coordinates. In some cases, however, this can be done, for example if the target has narrow, separated emission lines, as in a planetary nebula. In principle, one could specify the wavelength and then convert from pixel coordinates to celestial coordinates; this would be an image of the target in the light of a particular emission line. Or one could specify the celestial coordinates and then determine the wavelength at any pixel; this would be the spectrum at that point in the sky, although there would be overlapping spectra from other parts of the image.

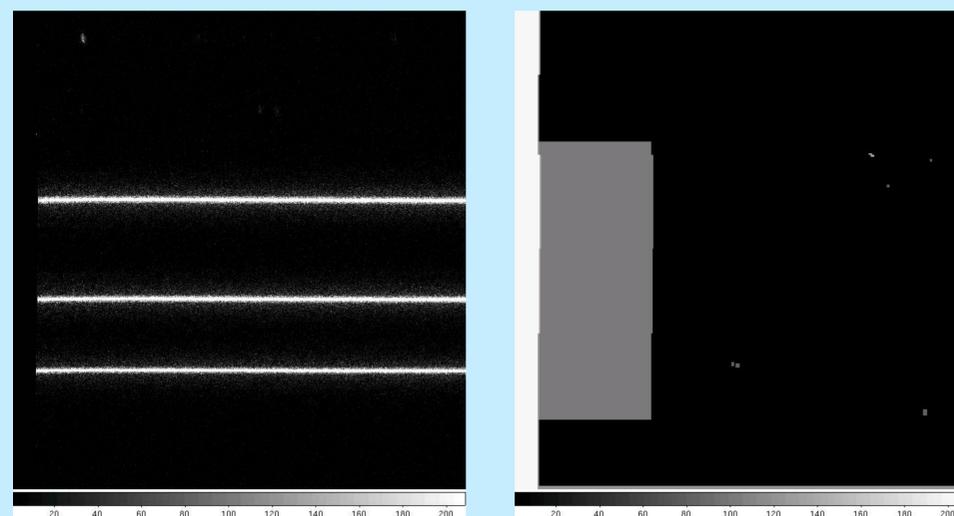
To allow for this option, COS images (`flt` and `counts` files) now include the keywords for a 3-D world coordinate system (`wcsaxes = 3`). The `corrtag` files only have a 2-D WCS because that is what is supported for the FITS pixel list format; the coordinates are wavelength and angle perpendicular to the dispersion.

The FUV channel uses Rowland gratings, so the dispersion should be linear, so keyword `ctype1` is ‘WAVE’. This works well for the medium dispersion gratings, but the low resolution grating actually needs a quadratic term which is currently not included.

The NUV channel uses flat gratings, so the dispersion should be computed from the grating equation. This is indicated by setting keyword `ctype1` to ‘WAVE-GRI’. Other keywords give the reference pixel number, wavelength at the reference pixel, dispersion, groove density, spectral order, and the incident angle onto the grating.

## DQ Array:

There is a data quality (DQ) image extension in the `flt` and `counts` FITS files. This image is used to flag regions within which the data should not be used, and some regions are flagged as information to the user. The two figures below show a portion of an NUV image, with the left ends of the three spectra on the left and the corresponding portion of the data quality array on the right. Accurate alignment of the DQ array with the science data is essential when combining files taken at different offsets, so that regions flagged as bad in one file can be filled in with data from another. This observation (la9g01luq) of the white dwarf G-191B2B is used by permission of David J. Sahnou, JHU.



## Wavelength Calibration:

The offset of a spectrum from the nominal location is determined by taking an exposure of a Pt-Ne lamp spectrum and comparing it with a lamp template spectrum. In order to use chi square to compare the two spectra, the data must be scaled because the exposure times of the lamp spectrum and lamp template spectrum may differ, and the backgrounds differ.

The data are emission-line spectra, and there are sometimes many local minima of chi square, and the lowest minimum is not always the correct one. The following algorithm is currently used. (1) Find the 10 deepest local minima in the RMS difference between the observed lamp spectrum and the template. (2) Some of these local minima will just be noise. To find and reject these, fit a quadratic to five points around each minimum, and reject those that don't have positive curvature in the fit. (3) Use chi square to select the best of the remaining minima.

For those cases where the algorithm doesn't give the correct shift, e.g. if the lamp spectrum is too faint or the background too high, the user can specify the shift or shifts via an input text file, and `calcos` will use those values.

## hstcos Package in PyRAF:

There are three tasks in the `hstcos` package in PyRAF. `calcos` is an interface to the Python executable `calcos.py`. `splittag` splits a `corrtag` file into multiple files by time. `x1d` extracts a 1-D spectrum, starting with the `corrtag` file, using the same code as in `calcos`.