Optical modeling of new lifetime positions for the Cosmic Origins Spectrograph (COS)

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In order to prolong the life of the detector in the FUV channel of the Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope (HST), the positions of the spectra are adjusted by offsetting targets in the cross-dispersion direction. Since the installation of COS in 2009, five Lifetime Positions (LPs) have been used, and a sixth is scheduled to be commissioned in late 2022. The location of each LP is chosen based on both the evolving detector gain sag and the optical properties of the spectrograph. The COS optical design was optimized for use at its initial Lifetime Position (LP1), and offsetting the spectra introduces aberrations which affect the spectral resolution. In order to understand the effects of these aberrations on the data quality, optical models have been constructed in order to predict the performance of the spectrograph over the permissible range of target offsets and grating focus values. This modeling work – and how it is used in combination with on-orbit data when determining where to locate new Lifetime Positions – is discussed.

Lifetime Positions

In order to maximize the life of the COS FUV cross delay line detector, spectra are placed on the active area at multiple cross-dispersion positions, or Lifetime Positions (LPs), to spread the gain sag effects over as wide an area as possible. At the beginning of HST Cycle 30 in October 2022, five LPs will be in use (Figure 1), with the choice of LP for a given observation determined by the grating, central wavelength (cenwave), and exposure length.

The optical design of COS was optimized for LP1 (zero arcsecond offset position), where essentially all ground calibration was done, and where all on-orbit observations were made from 2009 to mid-2012. Since July 2012, off-axis positions (LP2+) have been used for COS observations. The choice of each new Lifetime Position on the detector is a complex, multi-dimensional optimization problem. An ideal LP for a given choice of wavelength and cenwave must ensure that the spectrum falls on a part of the detector with high gain and minimal defects; has acceptable spectral resolution over a large bandpass; is optimized over all the cenwaves for the grating while the focus mechanism is within its allowable range; keeps the aperture mechanism within its allowable range; and minimizes unintended light from reaching the detector.

A crucial part of this is ensuring the resolving power of the spectrograph is high enough to allow COS to continue producing world-class science.

The calibration effort required, in both staff time and HST time, for commissioning a new LP is significant. Thus, any measures that help minimize the time needed will provide significant benefits.

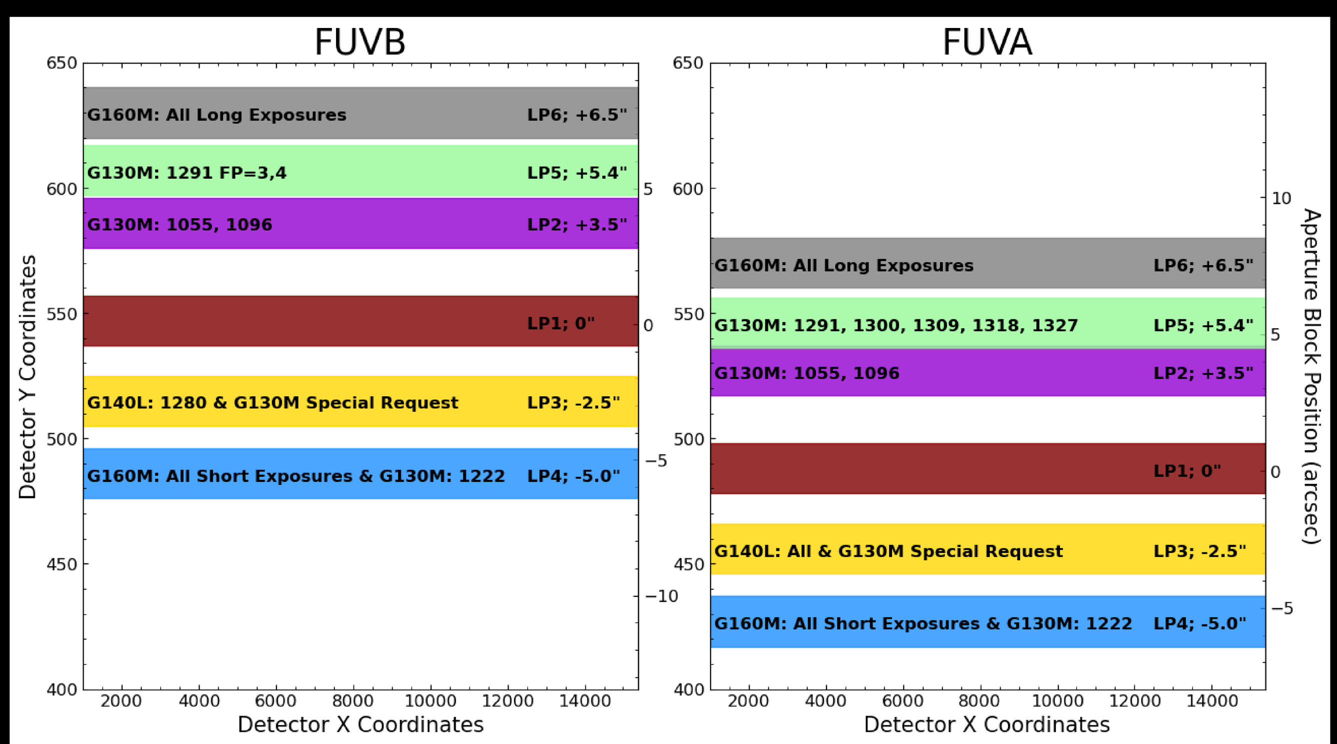

Figure 1 *A schematic view of how the spectra from LP1 – LP6 fall on both segments of the COS FUV detector. The locations relative to LP1 in arcseconds on the sky are labeled on the right side of each segment plot. Starting in October 2022, LP2 through LP6 will all be used regularly, and additional LPs will likely be used in the future.*

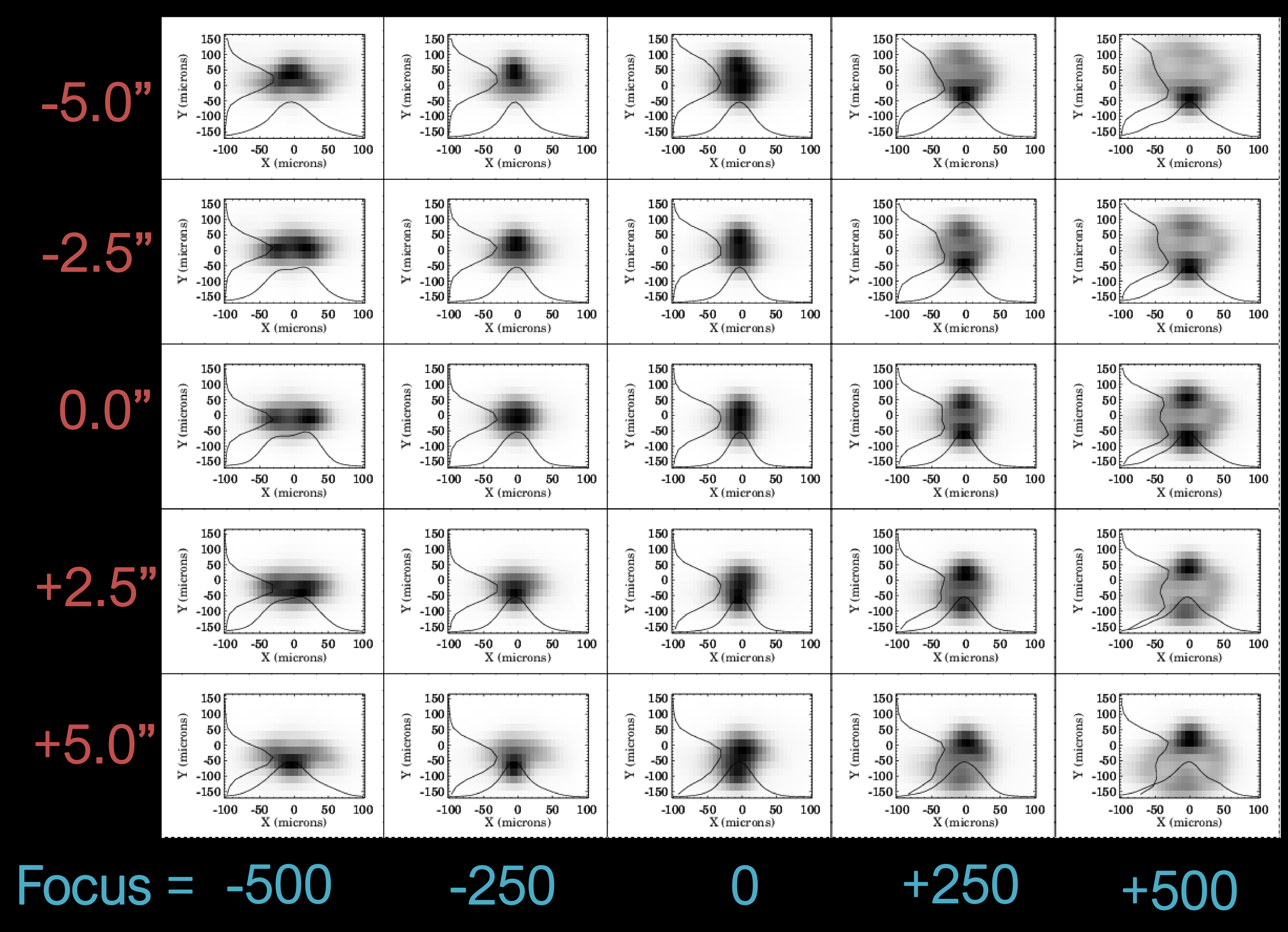

Figure 2 *An example set of model PSFs for G160M/1600 at 1600 Å. Each row shows a different cross-dispersion location (corresponding to LP), while each column is a different grating focus position. The width in the x (dispersion) direction, and thus the spectral resolution, varies as a function of both location on the detector and focus. One focus step corresponds to a 2.35 μm motion of the grating.*

Optical Models

CODE V Optical models of the COS instrument for LP1 that were developed while the instrument was on the ground have been updated and refined for each subsequent LP in order to take into account the configuration at these LPs. This includes changes to the offset position on the sky and grating wheel focus position. In addition, other enhancements have been made to make the models more robust, and the data products more organized.

In addition, a set of CODE V macros, along with analysis tools in Mathematica and IDL have been developed to generate and analyze Point Spread Functions (PSFs) created by the model. These tools can now be used to predict the performance of COS at potential LPs. As we continue to investigate additional strategies for extending the life of COS, these tools will be essential for helping to assess our options.

Although the data from the model does not provide a perfect representation of the observations, it allows qualitative comparisons of different options. Further refinements will be made in order to improve the match between the measured on-orbit data and the models.

Performance Predictions

Knowing what performance to expect at potential LP positions does not eliminate the need for on-orbit tests, but it can simplify the testing necessary. For example, each central wavelength has its own focus position at each LP. Determining the best focus for all cenwaves for each LP would require an unreasonable expenditure of HST orbits, so reliable models can help limit the on-orbit testing. The raytrace models can then provide an estimate of how much the relative focus position of the cenwaves for a given grating are expected to change at a new LP.

Figure 2 shows a grid of PSFs generated for G160M/1600 at 1600 Å. Changes in the properties of the PSF occur as both the cross-dispersion position (i.e. the LP) and the focus are changed. Even from this small sample of PSFs, the changes are clear. This confirms the known effect that for a given cenwave, the best focus depends on LP, and the maximum resolution at best focus decreases away from LP1.

Data from spots like these have been combined to create Figure 3, which shows more quantitatively how the resolving power changes with in focus and cross-dispersion location for this cenwave.

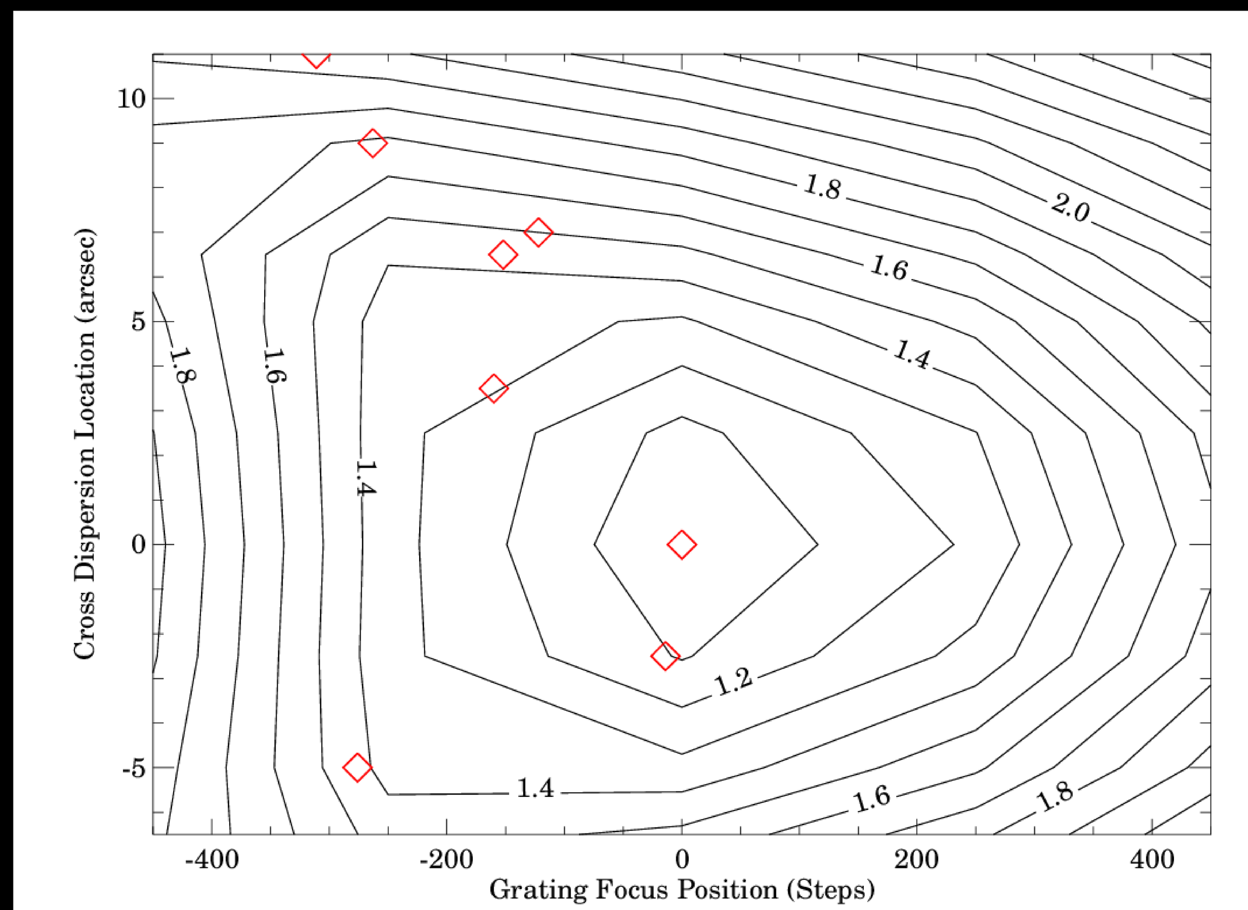

Figure 3 *Contours of relative FWHM (with the LP1 in-focus case being 1.0) of modeled Line Spread Functions (LSFs) as a function of grating focus and cross-dispersion for G160M/1600 at 1600 Å. Not only does the focus position shift with position, but the maximum attainable resolution decreases as spectra are moved away from LP1 and the LSF widens. Red diamonds mark the best focus positions as measured on-orbit.*

Acknowledgements

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