1D "CLEANing" of HST Spectra
(or, Converting Large Aperture Spectra to the Resolution of Small Aperture Spectra)

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Motivation
Large aperture spectra provide greater signal, but small aperture spectra have higher resolution (smaller line-spread function (LSF) wings). What if you wanted the best of both–maximum flux and resolution–and who wouldn’t? The simple method presented here can convert large aperture spectra to the resolution of small aperture spectra by removing the wings of the LSF without significant noise being added to the continua. In addition, this method/algorithm allows spectra taken through different apertures to be placed upon a common baseline for increased signal-to-noise (S/N). In marginal S/N cases, such as QSO absorption studies, this method is a particularly promising archive mining tool.

Method
The method is inspired by the 2D CLEAN method used in radio astronomy (Bennett, 1974), but adapted to 1D spectra. At the location of the highest flux peak in the spectrum, a wavelength-dependent line-spread function (LSF) of photons is subtracted and its location stored. The LSF of photons subtracted is a small fraction (∼1%) of the number of photons at this spectral location. Simultaneously, a new spectrum is created by adding a replacement LSF of photons at the original spectral location in the new spectrum. The replacement LSF could be a Gaussian of specified width, a delta-function, the LSF of another grating/echelle combination, or any other LSF (such as a ‘wings’ approximation of the original or alternate LSF). Successive passes through the remaining spectrum result in a residual spectrum that, after many such passes, begins to resemble a featureless continuum. Iterations are truncated when the maximum remaining flux is a pre-determined fraction of the original error vector; or, equivalently, when a certain size feature is no longer present in the spectrum. After this process has finished, a new spectrum is created by adding the remaining residual spectrum to the “cleaned” version.

Line-Spread Functions (LSFs)
The LSF describes the instrumental spectral distribution of an incident monochromatic emission source (delta-function) and is a function of aperture, grating, and wavelength. Sample HST/STIS first-order MAMA LSFs are shown in Figure 1 (taken from the STIS instrument handbook). With increasing aperture size and photon energy, the percentage of flux in the wings of the LSF increases significantly. HST spectral observers are forced to consider the trade-offs between apertures, often sacrificing flux (signal-to-noise) for resolution. For example, even though the reported (measured) Point Sources are nearly identical, 52” × 52” G140M observations were forced to select from apertures ranging from 4” to 113” transmissions and undocumented spectral resolution changes of greater than 10%.

Increased Resolution
Spectral resolution (Δλ/λ) is often defined by the full width at half maximum (FWHM) of the central Gaussian core of a line-spread function (LSF) and is only achievable for delta-function absorption or emission lines. To qualify the achievable resolution for a realistic astrophysical situation, we performed simulations with identical δ20 km/s absorption features of variable separation at 1216Å. We define the resolution R₀ as the separation between identical Gaussian absorption features at which the central maximum between the two minima has a flux deficit of 0.02% of the feature minima. Sample simulations for two separations are shown in Figure 1. The algorithm recovers the full extent of the absorption lines. The upper offset (400Å) spectrum is our delta-function replacement. The dot-dashed line shows the FOS/G270H spectrum degraded to the STIS/G230L resolution.

Marginal (1%) Increase in Continuum Noise
To examine the effects of our spectral cleaning on continuum noise, we “clean” a simulated S/N=20 per pixel STIS/G140M spectrum (52” aperture) over a continuum of 200Å (4000 pixels, 7" resolution) provided by the input+52” aperture LSF. The input spectrum, containing photon noise only, was convolved with the 52” aperture LSF, then “cleared” using a delta-function replacement. Figure 4 displays a histogram of the before and after continuum counts (left) and the differences (right). For a S/N of 20, the cleaned spectrum (right panel) is able to reduce the continuum to within 0.5%. In both examples, the non-Gaussian component of the residuals is 10% and is a small fraction (20%) of the intrinsic photon noise. Further optimization of our algorithm will only reduce this non-Gaussian noise component. The main point of this analysis is that even using the most extreme LSF, a delta-function, the added non-Gaussian noise is quite small. This is, of course, a major concern since these non-Gaussian residuals could be misinterpreted as larger deviations and residuumalized as real absorption or emission features.

Combining Spectra
At least some, all HST archival spectra should benefit from our spectral cleaning. However, of the 10,400 first-order STIS spectra in the archive, the "150x150 (7%) that were taken with larger (> 0.1") apertures will benefit the most from our spectral cleaning due to the significant LSF wings. Once "cleared", these larger aperture datasets can be combined with other "cleared" observations of the same target taken through other apertures without spectral degradation to produce higher signal-to-noise (S/N). In other words, this method allows archive users to place observations taken through different apertures onto a common frame. In addition, the negative impact of non-Gaussian wings of the LSF can be removed, resulting in increased resolution with minimal contribution to continuum noise. Our algorithm works for all HST modes for which the LSF is well known.

Conclusions
By removing the non-Gaussian wings of the LSF, our algorithm increases the resolution of HST archive spectra by as much as 70% for the STIS medium resolution gratings, while introducing ∼0.2% noise to the continuum. Our algorithm also allows spectra taken through different apertures to be combined in a way that actually increases the S/N and spectral resolution.