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Application of the Pixon Based Restoration to HST Spectra and Comparison to the Richardson-Lucy and Jansson Algorithms: Restoration of Absorption Lines

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Abstract. We discuss the application of the Pixon Based Image Restoration Method on spectroscopic HST data and compare the results with those obtained from the Richardson-Lucy and Jansson algorithms. In order to better evaluate the performance of the various algorithms we have also used artificial data.

1. Introduction

The HST spherical aberration is responsible for the large point spread function (PSF) already demonstrated in various papers in this volume. Because of the extended PSF, the two HST spectrographs (GHRS and FOS) suffered a significant throughput loss. As a result, the use of the larger apertures was often necessary, with obviously degraded spectral resolution. Our particular emphasis in this work is the restoration of absorption lines blurred by the large line spread function (LSF). An added complication to the problem is the fact that the LSF is very poorly known. The LSFs that are available to us are derived from the PSFs, which in turn are either deduced from observations (e.g., from FOC), or from models (e.g., TinyTIM). The real LSF of course changes with time and focus position, so the LSFs used for our analysis are only approximate.

2. The Methods

We have applied the Pixon Based Image Restoration Method (Puetter, this volume; Piña & Puetter 1993, 1992; Puetter & Piña 1993) to real and simulated HST Spectra. Both the Richardson-Lucy (Richardson 1972, Lucy 1974) and Jansson (1984) algorithms have already been used extensively for spectroscopic applications (Gilliland 1990, Morris et al. 1991). All three methods are nonlinear. An undesirable characteristic of most restoration techniques is the noise amplification, over-resolution and ringing. In spectra, these problems are manifested as narrow features. Ringing is especially bad in the vicinity of emission lines, where the slope of the continuum changes significantly. Since our emphasis is on the restoration of absorption lines, we have worked only with normalized spectra. This approach can be useful when the continuum does not change rapidly over the length of the LSF. The advantage of this technique is that we can impose upper and lower bounds, namely positivity and continuum. We can therefore restrict the algorithm from unnecessarily amplifying the noise in the spectrum. Our selection of the proper continuum will be a factor of error in our analysis and caution has to be used to minimize its effects. In all cases, the inclusion of the two bounds improves the restored spectrum quality significantly, compared to the unconstrained implementation.

3. Results

We demonstrate the method for a variety of simulated cases similar to those encountered in existing spectra. Cases of interest include weak absorption lines located in the vicinity of stronger lines,

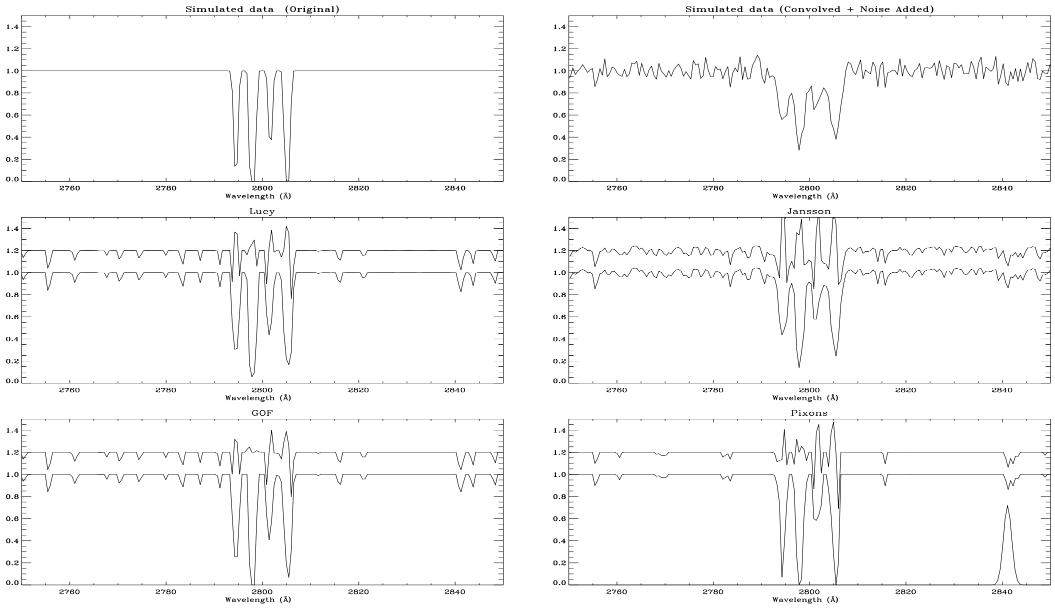

Figure 1. Restoration of a simulated Mg II interstellar line, with a high velocity feature at -375 km s^{-1}

isolated weak lines in relatively noisy spectra, and severely blended, strong saturated lines. Since most of the objects in our program were obtained with the FOS (including the $2''.0\times0''.25$ slit, the $1''.0$ circular, and the $4''.3$ aperture), we have used LSFs appropriate for these apertures for our simulations. Fig. 1 shows a simulated Mg II doublet with a high velocity component approximately 1.5 diodes (375 km s^{-1}) away from the main absorption. The line parameters used are $N_1 = 3\times10^{14}$ cm^{-2}, $b_1 = 50$ km s^{-1}, and $N_2 = 5 \times 10^{13}$ cm^{-2}, $b_2 = 50$ km s^{-1}. The top left panel illustrates the input spectrum. The top right panel shows the input spectrum after convolution with the LSF of the $2''.0\times0''.25$ slit and the G270H grating. Gaussian noise of the order of 8% is also added. The rest of the panels illustrate each one of the three methods. The GOF panel shows the restoration produced by a straight goodness of fit (GOF) criterion, without the Pixon algorithm. For all figures, the LSF used is illustrated at the bottom of the Pixon panel. Fig. 2 shows the same components, but separated only by approximately one diode element (200 km s^{-1}). The residuals with respect to the original input spectrum are plotted on top of each restored spectrum.

Table 1 contains a summary of the 3 methods examined here, for the different spectra. Overall the Pixon Based Image Restoration Method reproduces the original with higher accuracy and with fewer spurious features.

Table 1. Comparison of Spectral Restoration Algorithms. The χ^2 per degree of freedom is given for each of the restorations shown in Figs. 1 and 2.

Method	Fig. 1	Fig. 2
Pixon	0.60	0.86
Richardson-Lucy	0.73	1.25
Jansson	1.27	1.95

Figs. 3, 4, and 5 show examples of restored FOS spectra towards PKS 2251+11, 3C273, and 3C286, respectively. For all three figures, the top left panel illustrates the original spectrum and the

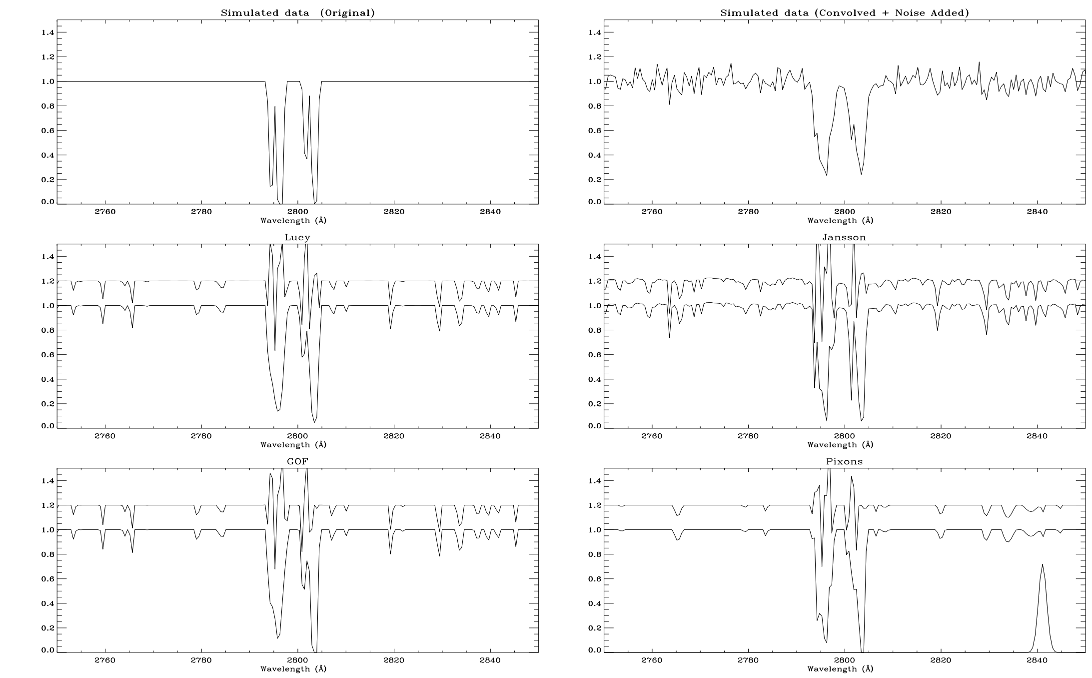

Figure 2. Restoration of a simulated Mg II interstellar line, with a high velocity feature at -200 km s^{-1} (significantly blended).

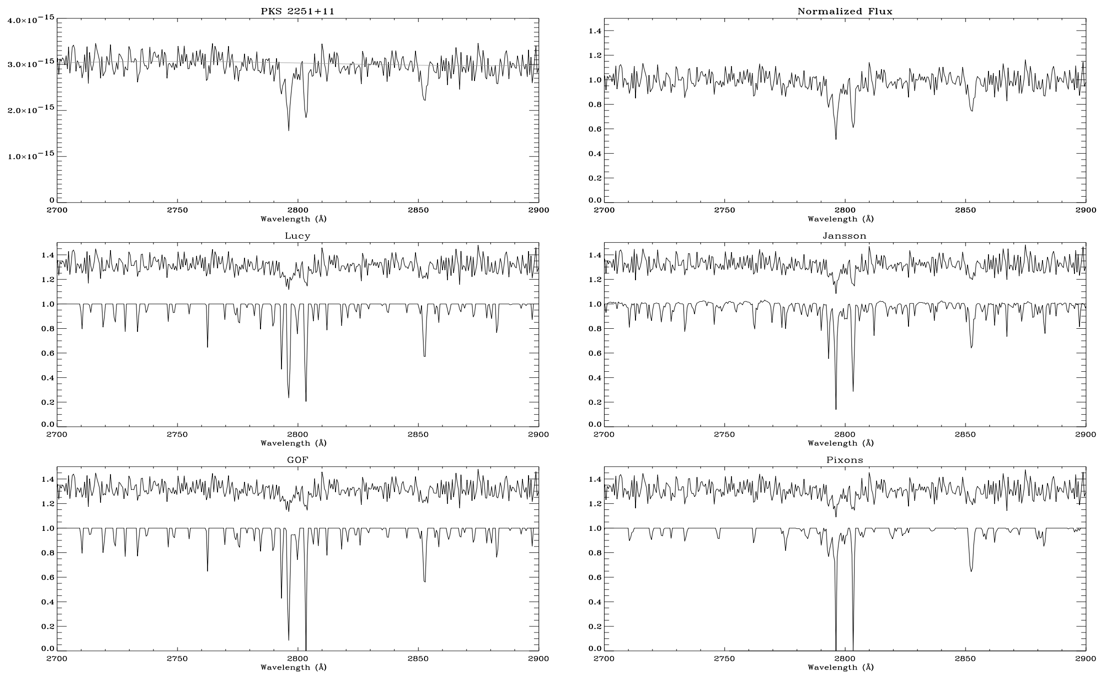

Figure 3. The FOS Spectrum of PKS 2251+11.

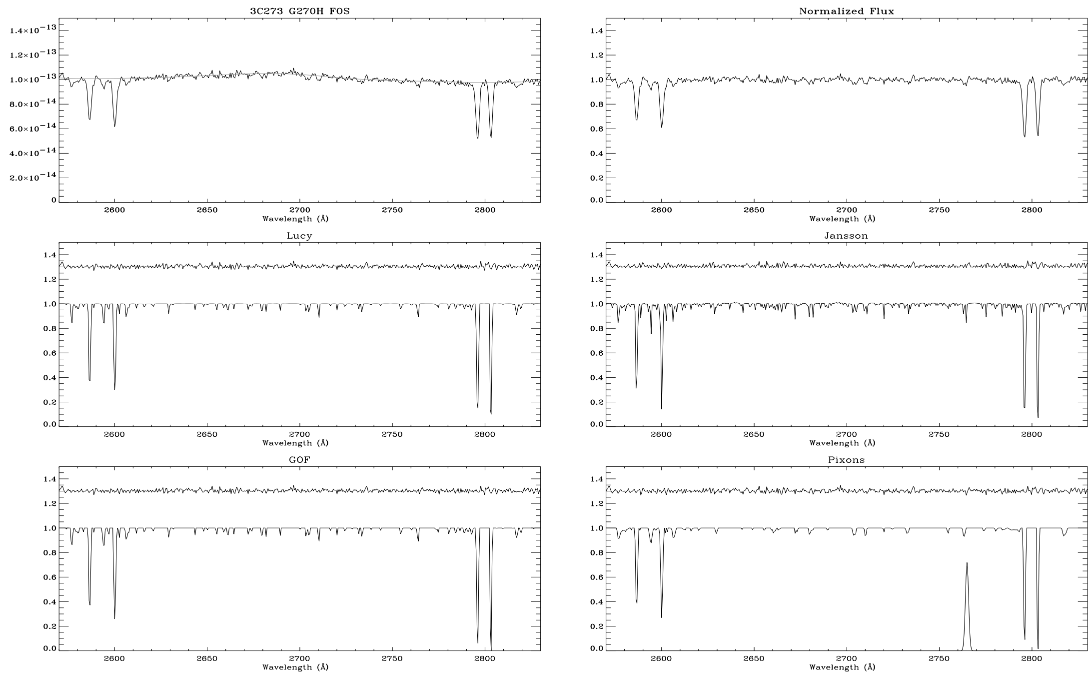

Figure 4. The FOS Spectrum of 3C273.

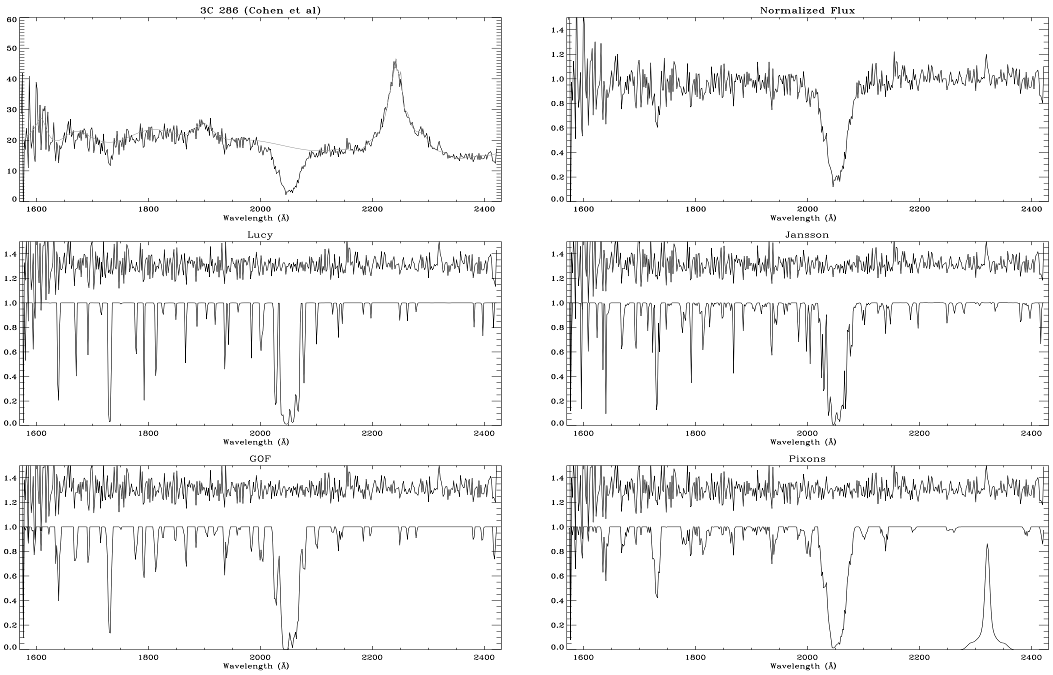

Figure 5. The FOS Spectrum of 3C286.

continuum used for the normalization, the top right the normalized spectrum, and the rest of the panels each method respectively. The residuals are plotted above the restored spectra.

A high velocity Mg II component associated with the Magellanic Stream was identified in the original spectrum, towards PKS 2251+11, by Bahcall et al. (1993) and Savage et al. (1993). The feature is clearly seen in the restored spectra. The 3C273 results from Fig. 4 can be compared with the higher resolution GHRS observations of 3C273 (Brandt et al. 1993, Savage et al. 1993), obtained with the G270M grating, through the Large Science Aperture (LSA). The Milky Way interstellar lines of Mn II, Fe II, Mg II and Mg I are clearly identified.

Fig. 5 shows the restored spectrum of 3C286 (Cohen et al. 1993). The object was observed with the low resolution grating G160L of the FOS and with the large $4\farcs3$ aperture. The Pixon based restoration has eliminated most of the spurious features will it has restored quite well the real lines. The two most prominent lines at the left of the damped Lyman α at $z = 0.692$ are the Lyman β and Lyman γ lines at the same z.

4. Summary

The Pixon Based Image Restoration Method provides us with a new tool for spectral restoration. This work, still in progress, indicates that the Pixon algorithm can recreate the original spectral features with higher accuracy compared with the Richardson-Lucy and Jansson methods. At the same time, it seems to be more effective in suppressing spurious features.

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