

Line Spread Functions for GHRS Spectra with the LSA (Pre-COSTAR)

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Abstract

The spherically aberrated point spread function of the *HST* provides input to the 2.0 arcsec LSA that is characterized by a sharp core and broad wings. The extended PSF wings contribute to a significant resolution degradation for spectra acquired through the LSA. The 0.25 arcsec SSA is matched in size to the spectroscopic resolution element; spectra taken in the SSA suffer a loss of throughput, but no significant resolution degradation. Through comparing spectra of a sharp-lined star acquired through both the LSA and SSA it is possible to derive the added line spread function (LSF) blurring of the LSA relative to the SSA. We report on empirical determination of the LSA spectral resolution degradation for three different wavelengths and four spectral elements of the GHRS.

I. Introduction

Knowledge of the differential LSA to SSA line spread function is of use for any quantitative analyses of spectral features in LSA spectra. The LSF is required to separate intrinsic line broadening from that imposed by the spectrograph and telescope. Any deconvolution of LSA spectra requires good knowledge of the line spread function. Since the SSA line spread function is known separately (arises primarily from the diode sampling, see e.g., Gilliland et al. 1992), then deriving empirical and differential LSA to SSA line spread functions provides the full LSF for both of the GHRS apertures to high accuracy.

A technique for deriving the differential blurring function if the true (SSA) and degraded (LSA) spectra are available was presented in Gilliland et al. (1992).

The following equation relates the observed spectrum, $\phi(x)$, the assumed point-spread-function, $P(y)$, blurring the true spectrum, $\psi(x)$:

$$\phi(x) = \int \psi(x-y) P(y) dy \quad (1)$$

This equation may be solved for the differential blurring function, if the true (SSA in this case) and observed (LSA) spectra are available.

The solution of equation (1) for the differential LSF can be expressed as the least-

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squares solution which minimizes χ^2 in the discretized case:

$$\chi^2 = \sum_i w_i \left(L_i - \sum_j P_j S_i \right)^2 \quad (2)$$

where L_i and S_i are the as-observed LSA and SSA spectra, and P_j is the desired differential LSF. Weights at the high S/N levels used here are set assuming Poisson statistics on the total number of counts per pixel. The extent of P_j is set by the projected size (in pixels) of the LSA. For the first order gratings this is 32, for the echelles a smaller number results because of internal demagnification. As discussed in Wahlgren et al. (1991) the extremely sharp-lined star χ Lupi (HD 141556) is ideal for defining the LSF for all GHRS spectral elements.

The solution given by equation (2) gives mathematically correct LSFs, but sometimes fails to yield a physically reasonable solution. Our observations use quarter-stepped spectra in which adjacent points are not independent. When relating LSA and SSA spectra through equation (2) solutions for P_j would sometimes exhibit a sawtooth instability which could reach large amplitude with alternate points in the LSF taking (non-physical) negative values. A simple and quite effective solution is to add a 2nd difference penalty term to equation (2) that enforces smoothness on the P_j :

$$+ \sum_j wp (P_{j-1} - 2P_j + P_{j+1})^2 / (P_{j-1} + P_j + P_{j+1}) . \quad (3)$$

Choosing the relative weight contribution, wp , too small (or zero) allows a sawtooth instability on the P_j ; taking wp too large leads to a broader core than appropriate for the differential LSF (P_j) and leads to an increase of the sum of equation (2). Through trial and error it was easy to find a value of wp that gave smooth P_j without degrading the fit of LSA and convolved SSA and LSF spectra. Solution for the P_j was obtained using a non-linear least-squares approach from Bevington (1969).

II. Differential LSA to SSA Line Spread Functions.

Figures 1 and 2 illustrate the LSF solution — specifically for ECH_B 2682Å paired LSA and SSA spectra acquired on 15 January 1993. Figure 1 shows the differential LSF that when convolved with the observed SSA spectrum yields the best match to the directly observed LSA spectrum. The LSA, convolved SSA and resulting difference spectra are shown in Figure 2. The rms of the difference spectrum is 1.7 percent of the mean intensity level. Given a S/N of about 100 per pixel for both the LSA and SSA spectra the difference error assuming only Poisson statistics should be ~1.4 percent. The derived LSF provides a near-Poisson limited result in this case. The minor excess noise could be attributed to residual flat-fielding errors from the FP-SPLIT solutions and possibly intrinsic changes in the stellar spectra.

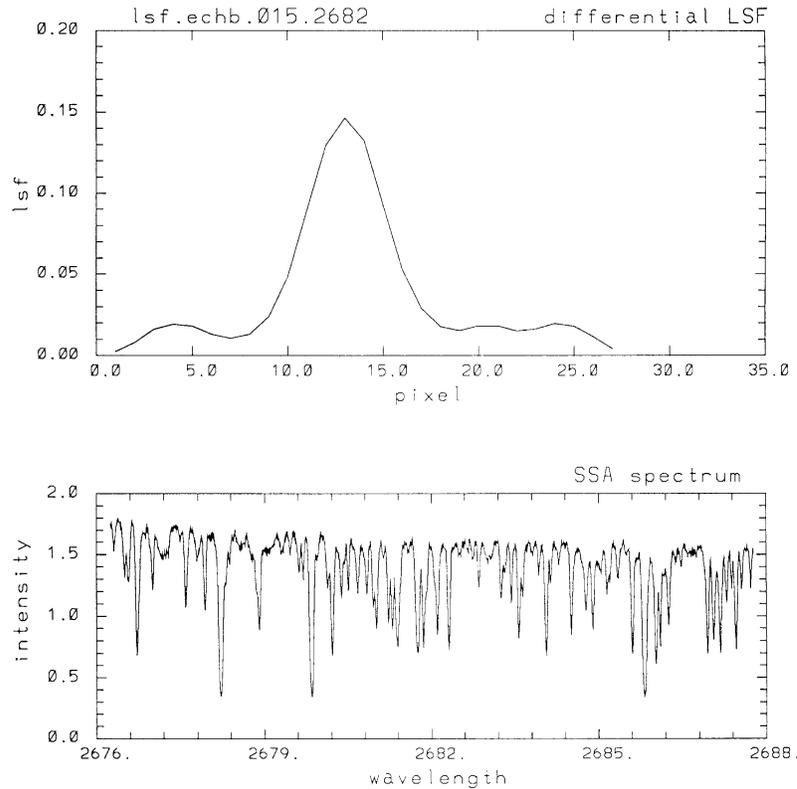


Figure 1: Differential LSF solution for ECHB data at 2682Å from 15 January 1993 is shown in the upper panel. Lower panel shows the observed SSA spectrum.

The Cycle 2 observations of CAL/HRS 3372 conducted on 15 Jan 1993 and 19 Feb 1993 gave good input to deriving differential LSA to SSA LSFs for the following wavelength-spectral element combinations: G160M—1360Å, G160M—1860Å, G200M—1860Å, G270M—2680Å, ECH_B—1868Å, and ECH_B—2682Å. The LSFs for these six cases are shown in Figure 3.

III. Full LSA Line Spread Function.

All of the above discussion was for the added blurring that results only from the large size (2.0 arcsec) of the LSA coupled with the spatial extent of light over the aperture. If one wishes simply to know the total LSF for the LSA (e.g., the observed profile given a spatial and spectral delta function source), then the intrinsic blurring of the spectrograph must be taken into account. The intrinsic spectrograph LSF may be referred to as the LSF of the SSA. Given the derived differential LSA to SSA LSF, the full LSA LSF is just the convolution of this differential LSF and the LSF of the SSA. Gilliland et al (1992) argued that the SSA line spread function could be well represented by a Gaussian of ~3.75 pixels FWHM (the Echelle LSF is similar but with slight additional wings).

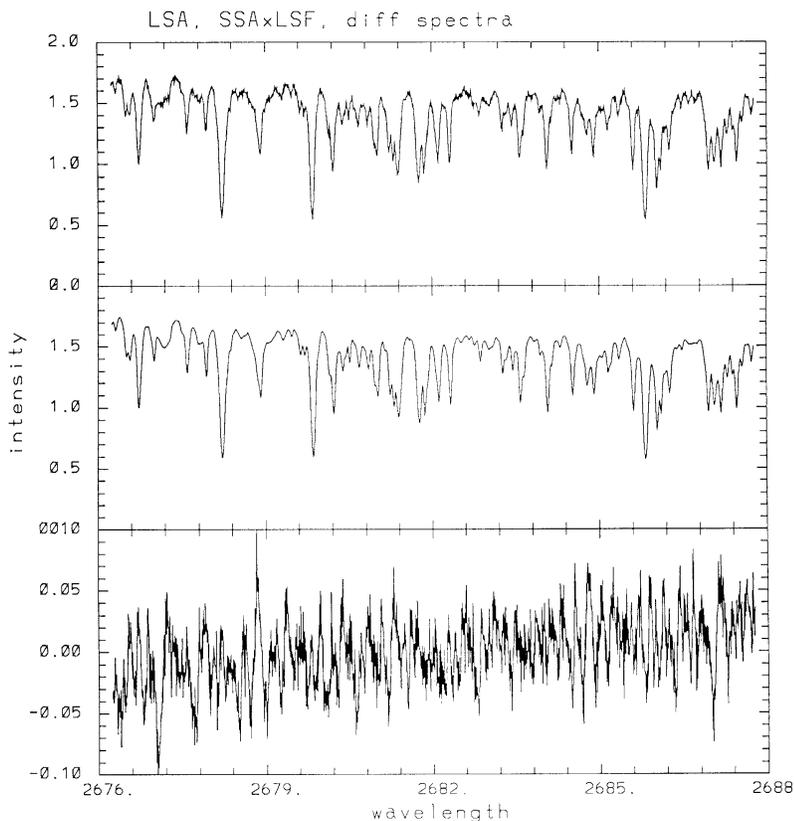


Figure 2: Upper panel shows the observed LSA spectrum of 15 January 1993. The middle panel shows the SSA spectrum after convolution with the LSF which should closely reproduce the LSA observations. Bottom panel is the difference spectrum showing errors only a little larger than expected from Poisson statistics.

IV. Discussion

By observing a sharp-lined stellar spectrum in both the LSA and SSA of the GHRS we have been able to reliably determine the large aperture differential line spread function which is assumed to represent the spatial PSF (contracted to one dimension along the spectrograph dispersion) at the aperture. The first order grating LSFs exhibit only minor changes with wavelength. There is no indication of a significant difference between the G160M and G200M LSFs at the common wavelength checked. Little difference is seen between these LSFs, and those derived separately using early 1991 data.

The ECH_B LSFs show significant differences at the two wavelengths. From comparison with a 1991 measurement it appears that the difference depends on position within an order ($m\lambda$). At 1868\AA ($m\lambda$ 8 percent below blaze peak) the internal demagnification in the echelle mode results in an LSF 23 pixels (70 percent of first order case) wide. At 2682\AA (more relevantly at $m\lambda$ of 5 percent above blaze peak) the LSF is 27 pixels (82 percent of the first order case) wide.

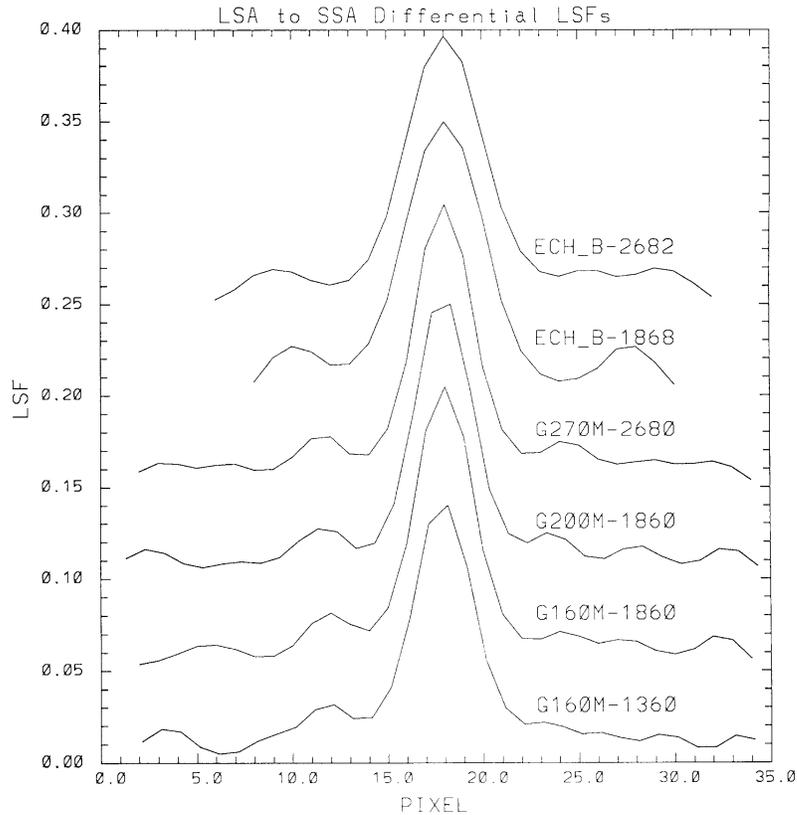


Figure 3: Differential LSFs (LSA to SSA) for the several wavelength-element combinations calibrated in 1993. LSFs for the first order gratings show only minor differences. The two echelle observations show significant differences; probably correlated with $m\lambda$.

The line spread functions derived for this report should be of use for studies that require line profile information and for deconvolution of LSA spectra. A more complete presentation of results may be found in the GHRS Instrument Science Report 055. The LSFs shown in Figure 3 should be used for GHRS data acquired at any time prior to the use of COSTAR.

References

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