The accuracy and repeatability of pipeline GHRS wavelength calibration

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Summary

The wavelengths of Pt-Ne lines measured in GHRS wavelength calibration data have been compared with the tabulated wavelengths of the lines to derive the absolute accuracy of the routine pipeline calibration. For the first order gratings the maximum value of the observed-expected wavelength averaged over each range was 0.09Å. However the difference between the measured and standard wavelengths varies little between the individual ranges of each grating and with time, based on two sets of identical calibration data taken in January and May 1992. The reproducibility of the calibration implies that with a simple shift applied to the wavelength scale an accuracy of ~0.02Å is achievable.

Analysis of the measured wavelengths of lines in one wavelength range of Echelle-B over a period of 1.3 days in January 1992 shows that routine accuracy of 0.03Å is achieved by the pipeline calibration, and as for the first order gratings this offset is rather stable. However there is still some systematic drift of the wavelengths which can be correlated with temperature, implying that further improvements in pipeline calibration could lead to greater accuracy.

1.0 Data sets

Wavelength calibration data from Proposal 2845 (1st order grating spectral calibration) for gratings G160M, G200M and G270M taken since the resumption of routine GHRS observing in January 1992, have been analyzed. The data consists of exposures at six wavelength settings for each grating obtained around January 14th and May 20th (in SMS 92103 and 92139 respectively). Table 1 lists the data files with brief details.

Although equivalent data for Echelle-B was not available, analysis of multiple exposures at the same wavelength setting (taken with the spectrum y-balance, ‘SPYBAL’) was made to determine the accuracy of routine wavelength
calibration. Twelve exposures obtained during proposal 3408 (Echelle Ripple) taken over a period of 1.3 days were analyzed. The long time span of this set of observations makes it ideal for searching for wavelength drifts.

2.0 Analysis
The details of the analysis are similar to those described in the previous report on wavelength calibration (Duncan et al., 1991). The data taken in January 1992 (see Table 1) had been wavelength calibrated by the PODPS pipeline using the erroneous dispersion constants reference table (ba412199z.cz6). These data were recalibrated using the new reference table (c3v1133gz.cz6), which is based on in-flight data, using CALHRS in IRAF.STSDAS.HRS. The data sets were analyzed using the standard IRAF analysis tools. For each grating and wavelength setting the wavelengths of the brightest lines were measured using SPLOT and fitting a single Gaussian. The .C0H and .C1H files were rebinned before SPLOT was used, and RESAMPLE with linear interpolation was employed. Only the brighter lines, with a peak height greater than 100 counts, were measured. The wavelength, strength and full width at half maximum (FWHM) of the fitted lines were recorded.

The fitted wavelengths of the lamp lines were compared with the reference wavelengths for a Pt-Ne lamp (Reader et al., 1989). A FORTAN program was written to read the output log file of SPLOT and compare the line positions against those in the Pt-Ne list. The program prompts for an offset between the measured line wavelengths and the standard wavelengths. This offset is easily determined by comparing the brightest line(s) in the fitted spectrum with the the strongest lines in the near ($\pm 1\text{Å}$) vicinity of the measured line wavelengths. The program then prints all the lines matched and allows lines to be dropped from the match if the discrepancy between measured and expected wavelength is large or the line width is large (indicative of a blended line). An output (ASCII) file of the values of standard wavelength, expected—observed wavelength and line FWHM for all matched lines is written. Figure 1 shows a typical plot of this output where the expected—observed wavelength is plotted against wavelength (for file Z0N60803T).

3.0 Results
For the first order gratings the number of lines analyzed ranged from 38 for the lowest wavelength region of G160M to 7 for the highest wavelength region of G270M. For each wavelength setting for each grating the mean of the expected—observed wavelength and the standard deviation on the mean was
computed in Å and in channels. The channel width was simply computed as the mean channel width from the wavelengths of the first and last channels of the wavelength file (.C0H). Figures 2-7 show the plots of expected—observed wavelength vs. central wavelength of the grating setting (the latter given simply by the wavelength of the central channel) for the three gratings at the two epochs. Table 3 lists the mean expected—observed discrepancy at each wavelength setting and epoch in terms of diodes (1 diode = 4 channels since the data were quarter sub-stepped). Table 4 lists the mean and standard deviation of the expected—observed wavelength for each grating based on the points presented in Figures 2-7.

The twelve Pt-Ne lamp exposures made with Echelle-B were similarly analyzed and the mean and standard deviation of the expected—observed wavelength were determined. Only five lines were sufficiently strong to be fitted in each exposure. Figure 8 shows the variation of expected—observed wavelength plotted as a function of the start time of each exposure. Table 5 presents the same results in terms of discrepancy between expected and observed line wavelengths in diodes. In addition two more Echelle-B SPYBAL spectra taken as part of proposal 3385 were also analyzed and the results are included in Table 5.

4.0 Conclusions
The obvious conclusion from this study is that the wavelength calibration delivered by the PODES pipeline, and depending on the dispersion constants reference table, is very good. For the first order gratings the maximum error encountered was 0.09Å; Table 4 lists the offsets averaged over all grating settings in terms of wavelength and diodes. However the situation is actually much better than these figures suggest since for each grating the offset is constant to within a small range. Examination of columns 3 and 4 of Table 3 shows that the offsets are remarkably constant. Therefore application of the figures in Table 4 should deliver wavelength good to ± 0.02Å (ie. 3 kms⁻¹ at 2000Å). This is a remarkable achievement and a credit to the builders of this spectrograph.

Some caution must be exercised in the blind application of the corrections listed in Table 4. The instrument may have undergone a random shift so that a check is always advised. The best way to perform such a check is to use the wavelength exposure taken with the SPYBAL. These calibration exposures occur at a set wavelength range (those marked with an asterisk in Table 3). Comparison of the wavelengths of the lines in these exposures with the standard Pt-Ne line wavelengths will then provide a shift which can be applied to the data. The very small variation of the shift as a function of wavelength seen
in Table 3 for each grating justifies the application of a simple shift correction. Two methods are suggested for determining the magnitude of the correction:

- simply compare the fitted wavelengths of one or more of the lines in the SPYBAL calibration spectrum with those from the Pt-Ne line list (Reader et al., 1989), exactly the procedure that is described here, and apply this as a linear wavelength shift to the data;

- determine the shift of the SPYBAL calibration spectrum against a spectrum synthesized from the Pt-Ne line list (which includes line strengths). Although the relative strengths of measured and tabulated lines do not always agree closely, then provided no great differences exist this should be a reliable technique. The cross correlation should perhaps be repeated with the new end point in case the synthetic spectrum produced from the line list has a strong line near the ends. This procedure can be achieved by using WSHIFT in STSDAS.GHRS.

In terms of the offset of the tabulated and measured line wavelengths measured in diodes, the Echelle-B data is not so well calibrated by the PODPS pipeline. The mean shift is 0.0341 Å (standard deviation 0.0067) [1.382 ± 0.272 diodes] for the 14 data sets analyzed (Table 5). It is probable that improved wavelengths can be obtained by adding this correction to the measured wavelengths. However a full analysis of all the Echelle-B spectral calibration data is required to confirm this. Again similar techniques could be applied for determining the value of the correction as for the first order gratings.

There is clearly a drift in the wavelength zero point for Echelle-B related to temperature, which is well shown in Figures 9 and 10 and is not corrected by the current pipeline calibration (involving the thermal constants table). For the carrousel stator temperature (CST) the drift, from a linear least squares fit to the points in Figure 9, is 0.0069 ± 0.0017 Å/°C (0.271 ± 0.067 diodes/°C) with a linear correlation coefficient of 0.787 for 12 points; for the optical bench temperature (OBBT), the least squares fit to the points in Figure 10 yields a drift of 0.0077 ± 0.0022 Å/°C (0.313 ± 0.087 diodes/°C) with a linear correlation coefficient of 0.750. The best fitting straight lines are shown on Figures 9 and 10. No correlation was found between the wavelength shift and the temperature of the DEB rear post amplifier (DEBTR), which is used to correct the thermal drift of this grating (see Ebbets, 1992, p.5-23). There clearly is some traceable thermal drift remaining for Echelle-B after correction by the DEBTR which could be incorporated in a refined thermal correction procedure.

From the measured FWHM of the lines, the mean FWHM of all lines measured for the first order gratings at both epochs was 1.073±0.032 diodes. Since
the aperture used for the comparison lamp observations (SC2) projects to one diode, this implies that the effect on the line spread function introduced by instrument smearing is very small. For the Echelle-B data, the mean FWHM of the lines was $1.145 \pm 0.030$ diodes. The larger value than the first order gratings is accountable by some demagnification of the echelle grating (see Gilliland et al., 1992).

**Acknowledgements**
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**References**
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Table 2. Details of data files used in Echelle-B analysis

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Table 3. Mean and standard deviation of (expected - observed) wavelength for first order grating settings

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* Wavelength range used for sybal.
Table 4. Mean and standard deviation of (expected - observed) wavelength for first order gratings

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Table 5. RMS on fit of reference wavelength v. line position for Echelle-B data

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List of Figures

1. Tabulated—measured wavelength ν. line wavelength for G160M spectrum centered at 1402Å from analysis of dataset z0n60803t.

2. Variation of the mean of the tabulated—measured wavelength at each grating setting for grating G160M for January 1992 data.

3. Variation of the mean of the tabulated—measured wavelength at each grating setting for grating G160M for May 1992 data.

4. Variation of the mean of the tabulated—measured wavelength at each grating setting for grating G200M for January 1992 data.

5. Variation of the mean of the tabulated—measured wavelength at each grating setting for grating G200M for May 1992 data.

6. Variation of the mean of the tabulated—measured wavelength at each grating setting for grating G270M for January 1992 data.

7. Variation of the mean of the tabulated—measured wavelength at each grating setting for grating G270M for May 1992 data.

8. Variation of the mean of the tabulated—measured wavelength against relative time of exposure start for Echelle-B data from proposal 3408.

9. Variation of the mean of the tabulated—measured wavelength for Echelle-B data against temperature of the optical bench bulkhead. The least squares best fit straight line is also shown.

10. Variation of the mean of the tabulated—measured wavelength of Echelle-B against temperature of the carrousel stator. The least squares best fit straight line is also shown.