XV. Systematic Errors in the SWP Wavelength Scale

The purpose of this note is to assess the absolute accuracy of the wavelength scales provided as part of the processed IUE SWP data taken with high dispersion and small aperture. The data used are echellograms of chemically peculiar HgMn stars and normal B and A stars obtained as part of my observing programs MVDSL and DGDSL. These stars are characterized by very sharp absorption lines of moderate strength, distributed over the entire wavelength range of interest (1250-2000Å). Although blending is a serious problem in the ultraviolet even for stars with v sini $\sim$ 0, many individual spectral features can be unambiguously identified in these spectra, their wavelengths can be accurately measured, and biases in such measurements due to unresolved blends are minimized.

All wavelength measurements were made with interactive computer routines written in the SOL and IDL languages on our Laboratory's PDP 11/40 computer. For a given image the central wavelengths of the strong Si II resonance lines, $\lambda\lambda$1533.44, 1526.72, were measured first. These gave a rough estimate of the quantity $\delta\lambda = \lambda$(measured) - λ (laboratory) of sufficient accuracy to allow the identification of Fe II lines and other features to be used for more precise measurements. This was followed by the measurement of approximately nine well-defined lines due primarily to Fe II multiplets 8 and 68 in the in the 1600-1650Å region. The average of these measurements for each image, denoted $\langle\delta\lambda\rangle_{1630}$, is listed in column 4 of Table 1. Column 3 lists the radial velocity for each image which contains components due to the star's radial velocity, the earth's heliocentric velocity and the IUE's geocentric velocity at the time of observation. The geocentric velocity component was calculated with E. Jenkins' (1979) recipe. I have verified the accuracy of his method (better than 0.2 km s^{-1}) by comparison to satellite velocities obtained, for a small number of images, directly from the GSFC orbit computation office. (Note, however, in Jenkins' Step 3, M must be converted to radians for use in calculating true anomaly, v, and v must be converted back to degrees for use in Step 4). Four of the HgMn stars (HR4072, 46 Dra, χ Lup and κ Cnc) are spectroscopic binaries whose radial velocities at the time of observation were calculated from orbital elements found in the literature. The normal stars θ Vir and π Cet are suspected spectroscopic binaries but I assume their velocity amplitudes are small (this assumption does not effect the basic conclusions drawn below).

Column 5 of Table 1 lists the measured values of $\langle\delta\lambda\rangle_{1630}$, corrected for all known components of radial velocity - i.e. the residual wavelength scale errors near 1630Å. The corresponding average radial velocity errors, $\langle\delta V_{rad}\rangle_{1630}$, are listed in column 6. As discussed below, I have established that the standard deviation in a single measurement of a single line in these images is $\sigma \simeq$ 0.02 - 0.03Å (5-7 km s^{-1}). The standard deviation in $\langle\delta\lambda\rangle_{1630}$, due to measurement errors and blending biases, is $\lesssim$ 0.01Å. By this standard, ten of the 26 images measured have very accurate wavelength scales in the 1600-1650Å region and three others deviate by only 3σ from laboratory wavelengths. Fifty percent of the images possess significant wavelength scale errors. In three cases (SWP 1331, 1332, 1333) the errors are enormous ($\gtrsim$ 0.5Å or 90-100 km s^{-1}). These three images, which were obtained very early in the program, have now been reprocessed as part of the current SWP ITF correction program. The systematic wavelength errors are very much smaller in the reprocessed data, suggesting that those large errors were artifacts of the data reduction procedures in use shortly after launch. Nevertheless, the errors are non-negligible even in the reprocessed images. It is possible that the apparent systematic wavelength errors might be due in part to errors in the adopted stellar radial velocities. However, this cannot explain the differential errors between closely spaced observations of the same star - e.g. θ Vir, SWP 1939 and 1940, taken 82 minutes apart. The systematic errors are evidently real and result either from intrumental effects (e.g. - thermal drifts of the position of the detector with respect to the optical axis of the spectrograph) or from inaccuracies of the data processing.

To assess the wavelength dependence of the errors detected near 1630Å, I measured a larger set of lines (mostly Fe II), distributed over the wavelength range 1250-2000Å in 13 of the images listed in Table 1. I confined these measurements in a given image to the properly exposed orders, since measured line positions in over-exposed orders have proven to be unreliable because of saturation effects. About 40 lines were measured in each image. Measurements of heavily exposed images were limited to the 1250-1700Å region; those of lightly exposed images were limited to 1600-2000Å. The measurements of two examples of each kind of image, corrected for radial velocity, are illustrated in figures 1 and 2. I have also illustrated in each case a linear relation, $\delta\lambda \propto \lambda$, normalized to the values of $\langle \delta\lambda \rangle_{1630} - V_{rad} \cdot \frac{\lambda}{c}$ at 1630Å. In all 13 images the $\delta\lambda \propto \lambda$ relation provides a reasonable (though not perfect) fit to the measured errors. That is the systematic errors in the SWP wavelength scale are, to a reasonable approximation, velocity-like. This same conclusion can be drawn from the data in columns 7 and 8 of Table 1. Here I have listed the average radial velocity error, $\langle \delta V_{rad} \rangle_{extended}$ of all the 40 or so lines measured in each of the 13 images. The largest measured difference between the values of $\langle \delta V_{rad} \rangle_{ex}$ and the corresponding values of $\langle \delta V_{rad} \rangle_{1630}$ is 4 km s^{-1} for SWP 1347. The difference is $\leq$ 2 km s^{-1} for 10 of the 13 images. These differences are not statistically significant. Column 8 of Table 1 lists the standard deviations, σ_{ex}, in a single measurement of δV_{rad} for a single line, based on the extended line-set data. These values of σ_{ex} are very consistent from image to image, regardless of the size of $\langle \delta V_{rad} \rangle_{ex}$. They reflect, for the most part, measuring errors and blending biases. The values of σ_{ex} indicate that the uncertainty in the measured positions of individual sharp lines is approximately 0.02-0.03Å. The uncertainties in $\langle \delta V_{rad} \rangle_{1630}$ and $\langle \delta V_{rad} \rangle_{ex}$ are approximately 2 km s^{-1} and 1 km s^{-1}, respectively. Thus, a difference between the two of 4 km s^{-1} amounts to less than two standard deviations.

To summarize the above discussion, an SWP wavelength scale can be characterized (and corrected) to first order by a single "velocity" parameter, which consists of the stellar radial velocity, the heliocentric and geocentric velocities and any systematic velocity-like errors. This parameter can be measured, with sufficient accuracy for most purposes, from a small set of well-defined spectral features. It is possible that deviations from the "velocity-like" characterization of systematic wavelength errors occur in some orders, but in the present data any such deviations are small and are difficult to distinguish from measurement errors and blending biases. Workers who require wavelength accuracies greater than 0.02-0.03Å in a particular order should be able to refine the wavelength scale of that order after a large number of lines in the order have been identified. In early type stars with v sini $\gtrsim$ 30 km s^{-1}, blending becomes so severe that all but the strongest absorption features lose their individual identities. In those cases it may be possible to derive the "velocity-like" scale correction from interstellar lines. Otherwise, one may simply have to accept the possibility of systematic errors in the wavelength scale as large as 20 km s^{-1} or so.*

Finally, I have also measured the wavelength scale errors for 11 small-aperture LWR images, using 9 of the strongest lines of Fe II multiplet 1 in the 2585-2630Å region. The results, tabulated in Table 2, are similar to those obtained with SWP. I have not yet investigated how the LWR errors scale with wavelength.

Reference

Jenkins, E. 1979, IUE Newsletter No. 5.

David S. Leckrone

*It has been suggested that the wavelength scale errors may be correlated with THDA, the detector head temperature of the instrument. If so, this parameter could be used to correct the images, independent of the nature of the observed object. I will search for such a correlation and report on the results in a future Newsletter.

TABLE 1. SWP WAVELENGTH SCALE ERRORS NEAR 1630Å IN HIGH DISPERSION IMAGES

(1) SWP #	(2) Star	(3) Total Vrad	(4) $\langle\delta\lambda\rangle_{1630}$	(5) $\langle\delta\lambda\rangle_{1630}-V_{rad}\frac{\lambda}{c}$	(6) $\langle\delta V_{rad}\rangle_{1630}$	(7) $\langle\delta V_{rad}\rangle_{ex}$	(8) σ_{ex}
1331	HR 4072	-24 km s^{-1}	-0.65Å	-0.52Å	- 96 km s^{-1}		
1331*	HR 4072	-24	-0.20	-0.07	- 13		
1332	HR 4072	-21	-0.61	-0.50	- 92	-89 km s^{-1}	6 km s^{-1}
1332*	HR 4072	-21	-0.14	-0.03	- 6	- 7	7
1333	ι CrB	-34	-0.73	-0.55	-100	-98	5
1333*	ι CrB	-34	-0.25	-0.07	- 12	-11	5
1334	ι CrB	-34	-0.19	-0.01	- 1	- 1	6
1339	46 Dra A	-16	-0.11	-0.02	- 4		
1340	46 Dra A	-17	-0.16	-0.07	- 12		
1341	χ Lup	-92	-0.47	+0.03	+ 6		
1345	μ Lep	+43	+0.22	-0.01	- 3		
1346	μ Lep	+47	+0.22	-0.04	- 7		
1347	κ Cnc	+41	+0.21	-0.01	- 2	- 6	5
1348	κ Cnc	+47	+0.24	-0.02	- 3	- 4	6
1352	κ Cnc	+82	+0.48	+0.03	+ 6	+ 3	5
1353	46 Dra A	-21	-0.10	+0.01	+ 3		
1354	ι CrB	-33	-0.16	+0.02	+ 4	+ 3	5
1939	θ Vir	+29	+0.21	+0.05	+ 9	+ 9	5
1940	θ Vir	+29	+0.11	-0.05	- 9		
1941	ν Cap	-10	-0.06	-0.01	- 1	0	5
1942	ν Cap	- 9	-0.07	-0.02	- 4	- 6	5
1943	ν Cap	- 9	-0.07	-0.02	- 4		
1944	π Cet	- 8	+0.09	+0.13	+ 24		
1945	π Cet	- 6	+0.01	+0.04	+ 7		
4688	χ Lup	+ 8	-0.02	-0.06	- 12	-13	5
4689	χ Lup	+ 8	-0.02	-0.06	- 12		

* Images reprocessed in 1980 with corrected ITF file and averaged reseau positions.

TABLE 2. LWR WAVELENGTH SCALE ERRORS NEAR 2610Å IN HIGH DISPERSION IMAGES

LWR#	Star	Total V_{rad}	$\langle\delta\lambda\rangle_{2610}$	$\langle\delta\lambda\rangle_{2610} - V_{rad}\frac{\lambda}{c}$	$\langle\delta V_{rad}\rangle_{2610}$
1289	ι CrB	-34 km s^{-1}	-0.08Å	+0.22Å	+25 km s^{-1}
1294	46 Dra A	-17	0.00	+0.15	+17
1295	χ Lup	-92	-0.74	+0.06	+ 7
1301	μ Lep	+45	+0.47	+0.08	+ 9
1302	κ Cnc	+44	+0.47	+0.09	+10
1308	ι CrB	-33	-0.09	+0.20	+23
1796	θ Vir	+29	+0.19	-0.06	- 7
1797	ν Cap	-10	-0.14	-0.05	- 6
1798	ν Cap	- 9	-0.13	-0.05	- 6
1799	π Cet	- 7	+0.03	+0.09	+10
1800	π Cet	- 7	+0.07	+0.13	+15

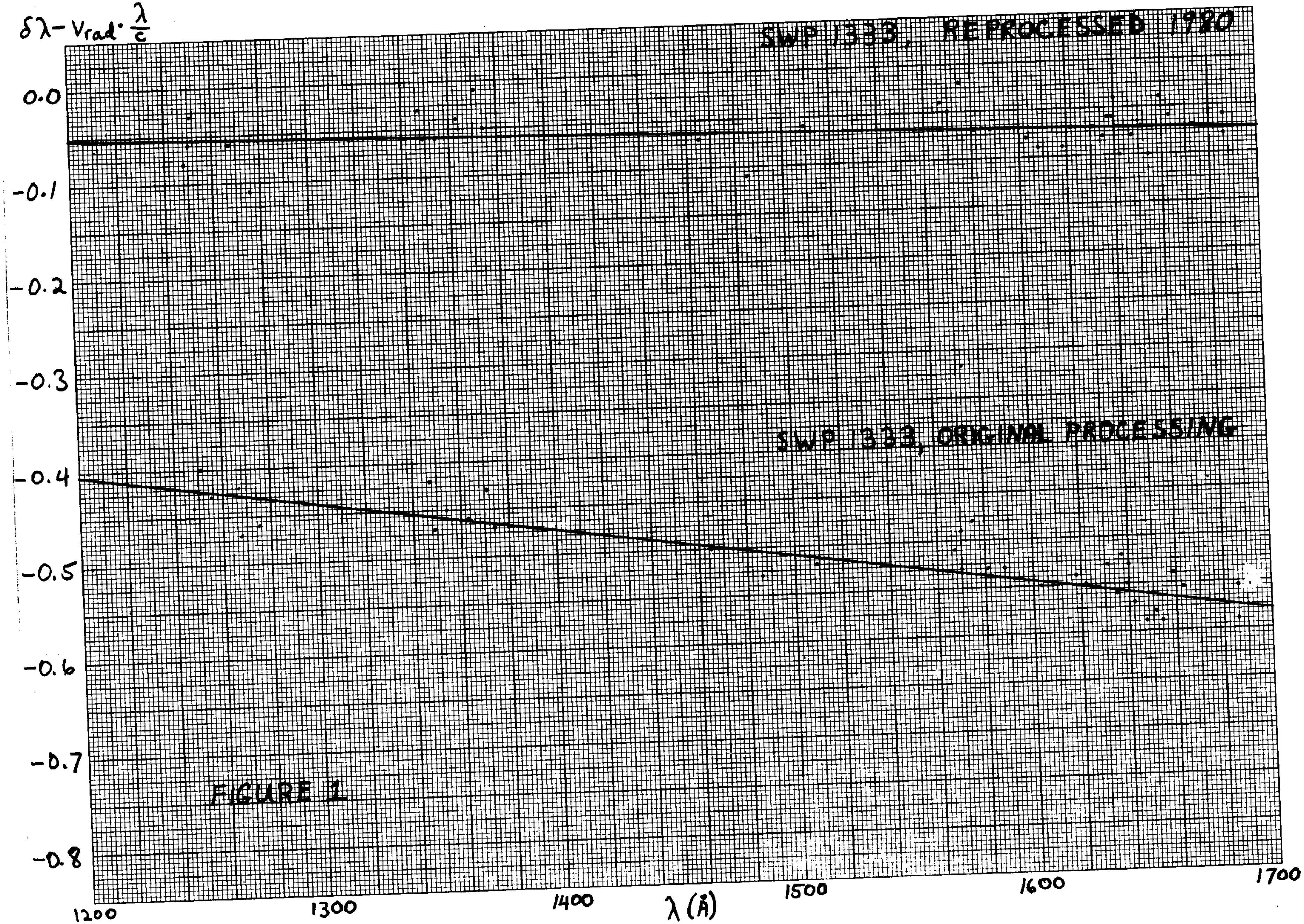
$\delta\lambda - V_{rad} \cdot \frac{\lambda}{c}$
SWP 1333, REPROCESSED 1980
SWP 1333, ORIGINAL PROCESSING
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
1200
1300
1400
1500
1600
1700
λ (Å)

FIGURE 1

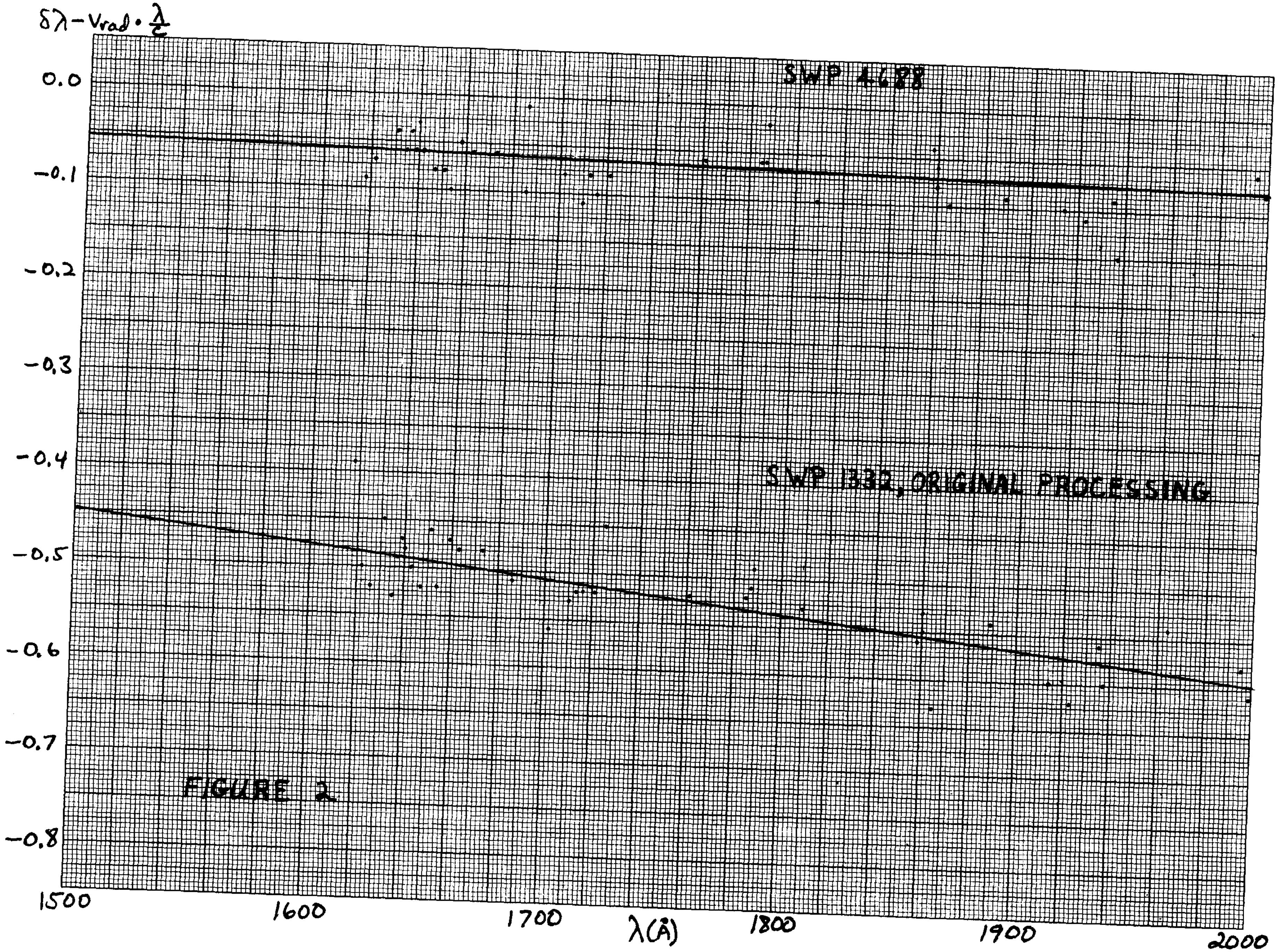
δλ - Vrad · λ/c
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
1500
1600
1700
1800
1900
2000
λ(Å)
SWP 4688
SWP 1332, ORIGINAL PROCESSING

FIGURE 2