A&A 561, A36 (2014)
DOI: 10.1051/0004-6361/201322287

Astronomy & Astrophysics

The LickX spectra★ (Research Note)

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Received 15 July 2013 / Accepted 19 November 2013

ABSTRACT

Context. Collections of stellar spectra, often called stellar libraries, are useful in a variety of applications in the field of stellar populations.

Aims. This is an attempt to improve the much-used Lick library of stellar spectra by removing jitter from the wavelength scale via cross-correlation, and calling the result the LickX library.

Methods. Each spectrum was cross-correlated with a template spectrum and a new wavelength solution sought. Low-order polynomials were fit to adjust the old scale to a new fit. Indices were measured, new standard star averages found, and adjusted averages derived for the program stars.

Results. The greatest gains in accuracy are expected for the fainter stars and stars of extreme surface temperatures; the bright K giant standard stars in LickX have the same uncertainties as Lick. The spectra and a table of index measurements in which repeated measurements are averaged are made available electronically.

Key words. catalogs – stars: abundances – galaxies: stellar content – stars: fundamental parameters

1. Introduction

A historically influential set of spectra based upon nonspectrophotometric observations carried out at Lick Observatory between 1972 and 1984 using the red-sensitive image dissector scanner (IDS; Robinson & Wampler 1972) and Cassegrain spectrograph at Lick Observatory. The spectra ranged from about 4000 to 6400 Å with spectral resolutions between 8 and 10 Å. The spectra were not fluxed, not even relatively, but were divided by a quartz-iodide tungsten lamp spectrum.

Stellar spectral libraries that, like the Lick library, span different metallicities as well as temperatures and luminosities, e.g., MILES (Sánchez-Blázquez et al. 2006; Falcón-Barroso et al. 2011), NGSL (Heap & Lindler 2010), and Indo-US (Valdes et al. 2004), are crucially important for a variety of applications in stellar populations. And, while it may seem that the Lick library might be outmoded, it is still useful in at least two regards. First, the accuracies of some indices with long wavelength spans (e.g., Mg_1, Mg_2) continue to be competitive with and in most cases exceed measurements take from CCD spectra. The exact reasons why remain obscure. Secondly, the target selection contains stars in odd but sometimes crucial corners of parameter space that are not well represented in other libraries.

A set of 11 pseudo equivalent width indices were measured by hand for stars and galaxies early on (Burstein et al. 1984; Faber et al. 1985; Burstein et al. 1986; Gorgas et al. 1993) and then expanded to a list of 25 indices (Worthey et al. 1994; Worthey & Ottaviani 1997). The latter papers also introduced an automated way to measure the indices wherein cross-correlation in the neighborhood of each index was used to center the index in wavelength, and where one particular observation of one giant, HR 6018, was used as the wavelength fiducial. Transferral of this wavelength scale to hot and cool stars was done stepwise through pairs of other template spectra.

2. Data available

In this paper, we reprocess the stellar spectra of the Lick library. The results are, first, increased accuracy in which the considerable uncertainties of wavelength scale are much reduced, and, second, a collection of spectra that can be used with fair ease by the community, since the improved wavelength scales are placed on a simple linear scale, albeit at the twilight of the usefulness of this set of spectra.

Methodologically, the spectra were subdivided into (typically) 15 pieces. Each was cross-correlated with a rebinned, high resolution spectrum, mostly synthetically generated from Buser & Kurucz (1992) machinery, but a cool M giant from the Elodie library (Prugneil & Soubiran 2001) was used to center the coolest stars. The wavelength scales of the templates are good to small fractions of an Ångstrom. The resulting shifts were displayed as a function of wavelength, wild points rejected, and fit with a polynomial. The polynomial most often used was a simple line, and the second most common case was an even more simple shift in the starting wavelength. This indicates that local shifts in the spectra were not as bad as had been assumed in the 1980s and 1990s, and that the automated method used then probably introduced noise in the wavelength placement for each index. On the other hand, many spectra did require quadratic or

★ Individual stellar spectra, in FITS files, and the ascii catalog of absorption feature index strengths are only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/561/A36 cubic solutions. If the solution was nonlinear, the spectrum was rebinned to be on a linear wavelength scale at the end.

During the process, beginning and ending wavelengths were also noted, and these were from time to time, more conservative than the original, so a few index measurements are trimmed in the LickX library compared to the original. As an indication of the jitter removed, the original wavelength scales and the cross-correlated versions we produce agree within a dispersion of σ = 3.3 Å, with approximate average accord in the blue, but with the new wavelength scales trending to about 0.5 Å redder at the red end of the spectrum.

The data are presented in FITS format files. Keywords *wcrval* and *wcdelt* give the wavelength of the first pixel in Angstroms, and the difference in wavelength between any two pixels in Angstroms per pixel, respectively. Occasionally, keywords *wlimit1* and *wlimit2* were inserted. These give the blue and red wavelengths, respectively, that delimit the bounds of what we consider the useful portion of each spectrum. They are often more restrictive than those generated by the automated algorithm (the algorithm finds a spectrum endpoint by testing for the presence of 10 consecutive pixels greater than 1/2000 the number of counts in the maximum pixel).

When the revisions of the spectra were complete, some spectral indices were measured. The indices are the 25 from Worthey et al. (1994), Worthey & Ottaviani (1997), with wavelength definition updates from Trager et al. (1998), some of the 79 indices given by Serven et al. (2005) that fall into the spectral range of the Lick spectra, three emission line indices from González (1993), and the modified $H\beta_0$ index of Cervantes & Vazdekis (2009) for a total of 63 spectral indices. The definitions are summarized in Table 1. The spectra were smoothed a small amount in the middle of the spectral range, so that they nowhere fell below an instrumental resolution equivalent to a velocity dispersion of 200 km s^{-1} for reasons of eventually producing a consistent set of spectra indices at this resolution. The smoothing had negligible effect on the indices.

There are 455 unique stars amongst the 1043 spectra, for the most part including a set of line strength standard stars observed in each of the 61 observing runs except for run 53 (HR 489, HR 1805, HR 2002, HR 2600, HR 3905, HR 6018, HR 6770, HR 7429, HR 7576). Data were not obtained in some runs. As in Worthey et al. (1994), these line strength standards define the system and then were used to generate additive corrections on a run by run basis if the standard stars in any particular run and in any particular index were statistically different from the grand average. A difference from Worthey et al. (1994) is that the averaging of multiply-observed stars was done using the Tukey biweight (Tukey 1958) as estimator for location and scale, as opposed to outlier-culled means and standard deviations. The biweight scales performed on the wavelength-rectified spectra were systematically smaller than the previous standard deviations measured from the unrectified spectra, and this tended to increase the number of run corrections. Another detail is that runs 8 and 53 had insufficient standard star observations for good statistics, and so the whole list of stars (less those two runs) were used as secondary standards to correct the indices from those two runs. The single-measurement uncertainties listed in the Table 1 are biweight scales, which reduce to standard deviations in the case of Gaussian random statistics.

Figure 1 gives a sample of the agreement between the old automated measurement and the results of simply measuring the newly cross-correlated specra using the new wavelength scales, for two spectral indices with broad dynamic range, Hβ and Na D,

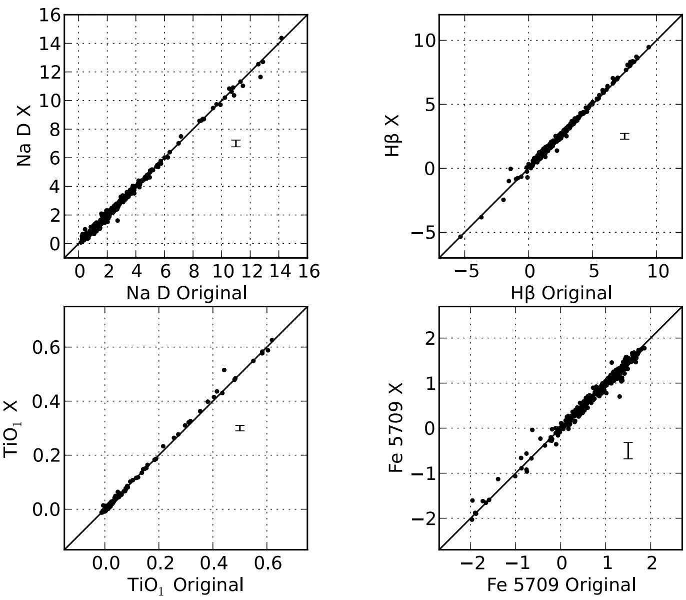

Fig. 1. Example indices (Hβ, Na D, TiO_1, and Fe5709) averaged from the original Lick library and from the new wavelength rectified version. Single-measurement error bars are shown for comparison. Apparently, the errors induced by wavelength scale changes are almost random, with no systematic drifts, with amplitudes comparable to, but somewhat smaller than, the single-measurement error.

an index that should be insensitive to wavelenth errors, TiO_1, and an index with small dynamic range, Fe5790. No systematic trends are apparent. Quasi-random scatter is clearly evident, though at a level less than the single-measurement error. It is expected, of course, that the newer versions are incrementally more accurate than the old.

The library of spectra and the 63 averaged indices with errors are available at the CDS.

Acknowledgements. The authors gratefully acknowledge the legacy of David Burstein, without whose labors at the telescope these spectra would never have been recorded, and dedicate this paper to his memory. We also thank former Washington State University undergraduate Angela "A.J." Marino, whose enthusiasm for polynomial fitting ensured the success of this effort.

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Table 1. Single measurement index uncertainty and index definitions.

Index	σ^a	Units	Definition references	Index passband^b	Blue pseudocontinuum^b	Red pseudocontinuum^b
CN_1	0.019	mag	1	4142.125–4177.125	4080.125–4117.625	4244.125–4284.125
CN_2	0.021	mag	1	4142.125–4177.125	4083.875–4096.375	4244.125–4284.125
Ca4227	0.315	Å	1	4222.250–4234.750	4211.000–4219.750	4241.000–4251.000
G4300	0.373	Å	1	4281.375–4316.375	4266.375–4282.625	4318.875–4335.125
Fe4383	0.451	Å	1	4369.125–4420.375	4359.125–4370.375	4442.875–4455.375
Ca4455	0.301	Å	1	4452.125–4474.625	4445.875–4454.625	4477.125–4492.125
Fe4531	0.434	Å	1	4514.250–4559.250	4504.250–4514.250	4560.500–4579.250
$C_2$4668	0.674	Å	1	4634.000–4720.250	4611.500–4630.250	4742.750–4756.500
Hβ	0.229	Å	1	4847.875–4876.625	4827.875–4847.875	4876.625–4891.625
Fe5015	0.485	Å	1	4977.750–5054.000	4946.500–4977.750	5054.000–5065.250
Mg_1	0.010	mag	1	5069.125–5134.125	4895.125–4957.625	5301.125–5366.125
Mg_2	0.010	mag	1	5154.125–5196.625	4895.125–4957.625	5301.125–5366.125
Mg *b*	0.271	Å	1	5160.125–5192.625	5142.625–5161.375	5191.375–5206.375
Fe5270	0.286	Å	1	5245.650–5285.650	5233.150–5248.150	5285.650–5318.150
Fe5335	0.274	Å	1	5312.125–5352.125	5304.625–5315.875	5353.375–5363.375
Fe5406	0.201	Å	1	5387.500–5415.000	5376.250–5387.500	5415.000–5425.000
Fe5709	0.181	Å	1	5696.625–5720.375	5672.875–5696.625	5722.875–5736.625
Fe5782	0.214	Å	1	5776.625–5796.625	5765.375–5775.375	5797.875–5811.625
Na D	0.236	Å	1	5876.875–5909.375	5860.625–5875.625	5922.125–5948.125
TiO_1	0.010	Å	1	5936.625–5994.125	5816.625–5849.125	6038.625–6103.625
TiO_2	0.009	Å	1	6189.625–6272.125	6066.625–6141.625	6372.625–6415.125
Hδ_A	0.779	Å	2	4083.500–4122.250	4041.600–4079.750	4128.500–4161.000
Hγ_A	0.555	Å	2	4319.750–4363.500	4283.500–4319.750	4367.250–4419.750
Hδ_F	0.451	Å	2	4091.000–4112.250	4057.250–4088.500	4114.750–4137.250
Hγ_F	0.298	Å	2	4331.250–4352.250	4283.500–4319.750	4354.750–4384.750
CO4685	0.822	Å	3	4626.400–4743.300	4557.300–4589.500	4805.100–4835.300
CO5161	0.169	Å	3	5154.300–5167.300	5108.400–5138.800	5188.400–5202.000
CNO4175	0.958	Å	3	4129.400–4219.800	4082.500–4123.300	4243.300–4284.200
Mg4780	0.302	Å	3	4760.800–4798.800	4738.900–4757.300	4819.800–4835.500
Si4101	0.316	Å	3	4093.300–4107.800	4057.900–4075.300	4111.500–4131.000
Si4513	0.364	Å	3	4490.800–4534.600	4448.700–4487.600	4541.100–4572.700
S4693	0.261	Å	3	4680.600–4704.400	4652.200–4677.300	4717.600–4737.700
K4042	0.285	Å	3	4035.900–4047.500	4014.900–4029.000	4054.700–4070.400
Sc4312	0.381	Å	3	4303.000–4320.700	4286.100–4300.600	4335.800–4354.400
Sc6292	0.341	Å	3	6265.100–6318.800	6199.200–6231.100	6320.900–6366.500
Ti4296	0.334	Å	3	4283.600–4308.200	4253.800–4274.400	4324.500–4343.000
Ti4533	0.180	Å	3	4525.300–4541.100	4486.300–4506.200	4548.700–4561.300
Ti5000	0.352	Å	3	4973.100–5026.100	4930.600–4959.400	5035.400–5052.500
V4112	1.193	Å	3	4086.400–4138.500	4057.100–4074.300	4145.000–4160.500
V4928	0.180	Å	3	4919.600–4937.400	4899.800–4914.800	4951.800–4965.200
Cr4264	0.532	Å	3	4246.800–4281.300	4179.300–4195.600	4310.700–4334.700
Cr5206	0.149	Å	3	5198.900–5213.600	5130.000–5149.200	5240.300–5257.000
Mn4018	3.188	Å	3	3992.600–4044.400	3940.900–3962.300	4096.300–4121.500
Mn4061	0.372	Å	3	4443.300–4477.700	4386.800–4406.900	4506.100–4530.300
Mn4757	0.252	Å	3	4741.500–4773.400	4715.600–4737.800	4792.400–4812.100
Fe4058	0.902	Å	3	4037.900–4078.400	4009.000–4031.100	4107.600–4125.700
Fe4930	0.273	Å	3	4907.000–4943.800	4894.500–4907.000	4943.800–4954.500
Ni4292	0.392	Å	3	4279.600–4305.400	4260.900–4275.300	4307.400–4323.600
Ni4910	0.235	Å	3	4897.400–4922.100	4879.300–4895.800	4953.200–4969.400
Ni4976	0.227	Å	3	4966.000–4986.300	4951.500–4964.400	5016.800–5028.900
Ni5592	0.210	Å	3	5578.300–5605.400	5521.100–5542.700	5612.600–5632.600
Cu5217	0.218	Å	3	5209.100–5225.300	5160.900–5186.900	5247.500–5275.800
Cu5780	0.149	Å	3	5772.300–5787.300	5720.100–5753.200	5808.000–5830.800
Zn4720	0.207	Å	3	4708.700–4731.500	4652.700–4670.000	4755.400–4775.500
Ba4552	0.169	Å	3	4545.400–4558.500	4522.200–4535.000	4559.500–4578.800
Ba4933	0.190	Å	3	4922.800–4943.300	4902.700–4916.100	4967.200–4992.700
Ba6142	0.192	Å	3	6130.700–6152.600	6105.800–6128.200	6176.300–6209.600
Sr4076	0.424	Å	3	4069.000–4082.200	4038.400–4055.600	4105.300–4126.800
Eu4592	0.165	Å	3	4584.800–4598.800	4533.500–4550.800	4626.300–4645.700
Hβemiss	0.154	Å	4	4851.320–4871.320	4815.000–4845.000	4880.000–4930.000
O3emiss1	0.294	Å	4	4948.920–4987.920	4885.000–4935.000	5030.000–5070.000
O3emiss2	0.160	Å	4	4996.850–5016.850	4885.000–4935.000	5030.000–5070.000
Hβ_0	0.261	Å	5	4839.275–4877.097	4821.175–4838.404	4897.445–4915.845

Notes. [a] Expected single-measurement uncertainty for most stars in the library based on the line strength standard star observations. [b] The wavelength spans for pseudocontinua and index passbands are given in units of Å.

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