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Validation of LAMOST Stellar Parameters with the PASTEL Catalog

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Abstract Recently the first data release (DR1) of The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) has been made available for the public. It is the largest stellar spectra dataset in the world so far. We adopted the PASTEL catalog combined with SIMBAD radial velocities as testing standard to validate the DR1 stellar parameters (effective temperature $T_{\rm eff}$, surface gravity $\log g$, metallicity $[{\rm Fe/H}]$ and radial velocity $V_{\rm r}$). We made cross-identification of the DR1 catalogs and the PASTEL catalog and got a sample of 422 stars. After applying problematic data reduction and reasonable constraint to the sample, we compared the stellar parameters from DR1 and PASTEL and showed that DR1 results are reliable under certain condition. We derived dispersion of 110 K, 0.19 dex, 0.11 dex and 4.91 $\rm km\,s^{-1}$ in specified effective temperature ranges, for $T_{\rm eff}$, $\log g$, $[{\rm Fe/H}]$ and $V_{\rm r}$ respectively. Systematic error is negligible except for that of $V_{\rm r}$. Also, for PASTEL $[{\rm Fe/H}] < -1.5$, metallicities in DR1 are systematically higher than those in PASTEL.

Key words: stars: fundamental parameters — astronomical data bases: catalogs — astronomical data bases: surveys

1 INTRODUCTION

The LAMOST, also called the Guoshoujing Telescope, is a special quasi-meridian reflecting Schmidt telescope located in Xinglong Station of National Astronomical Observatories, Chinese Academy of Sciences (NAOC) (Cui et al. 2012). The formation and evolution of galaxies is one of the most important astrophysical subjects at the moment. The Milky Way provides us an excellent example to study in detail. The LAMOST emerged at the right moment. Its large aperture and wide field of view coexist benefiting from the special design, which make it a powerful tool for this subject (Zhao et al. 2012; Deng et al. 2012).

After two years' test observation since the national acceptance in 2009, The LAMOST pilot survey began on October 24, 2011 and terminated on June 24, 2012. The following regular survey started on

September 28, 2012 and finished its first year mission on June 15, 2013. In 2013 July, DR1 of LAMOST was available for the public. The DR1 consists of 2,204,860 spectra of stars, quasars, galaxies and some other unknown objects. 717,660 of these spectra were acquired during the pilot survey, while the rest were from the regular survey. To extract stellar parameters from such large amount of spectra, an automated stellar parameter pipeline — ULySS was developed (Wu et al. 2011). They adopted the ULySS software (Koleva et al. 2009) to analyze the LAMOST spectra and derived full set of stellar atmospheric parameters ($T_{\rm eff}$, $\log g$, [Fe/H]) and radial velocities. There are 1,944,406 spectra of stars in DR1 catalogs, but only 1,085,404 of them have full set of stellar atmospheric parameters and radial velocities.

Before we use these stellar parameters to explore our Galaxy, we need to test them to see if they are reliable. The PASTEL catalog provides us an excellent testing standard. It is a catalog of stellar atmospheric parameters of tens of thousands stars with original bibliographies. Determination of stellar parameters in the catalog was based on analysis of high resolution and high signal-to-noise (S/N) spectra (Soubiran et al. 2010). We made cross-identification of the DR1 catalogs and the PASTEL catalog. Detail information about the cross-identification results will be given in Section 2. Then we compare the stellar parameters from the DR1 catalogs and the PASTEL catalog. During the comparison, we take the PASTEL parameters and SIMBAD radial velocities as "ground truth". We will show the comparison results in Section 3. Finally we will give a summary of our work in Section 4.

2 CROSS-IDENTIFICATION AND THE SAMPLE FOR VALIDATION

2.1 Cross-identification

In order to compare stellar parameters from DR1 and PASTEL, we need the cross-identification results of the DR1 catalogs and the PASTEL catalog. The PASTEL catalog is regularly updated. The version that we used is 17-May-2013, consists of 52,045 entries of 26,657 individual stars. Due to the position offsets of the bright stars observed by the LAMOST (H.-T. Zhang et al. 2013, private communication), we expanded the search radius to 10 arcsec. Then we checked the results one by one according to the photometry data in the DR1 catalogs and the PASTEL catalog and images around the objects from SIMBAD database. After removal of the false results, we got a sample of 422 stars.

2.2 Stellar Parameters in the Sample

Full set of stellar atmospheric parameters and radial velocities of more than 300 stars in the sample are available in the A, F, G and K type stars catalogs of DR1, and the rest have only radial velocities. $T_{\rm eff}$ of 420 stars are available in the PASTEL catalog, while $\log g$ and $[{\rm Fe/H}]$ of only about 150 stars in the sample are available in the PASTEL catalog, which make us short of testing standards for $\log g$ and $[{\rm Fe/H}]$. We will see this situation more clearly in section 3. We retrieved radial velocities of 323 stars in the sample from SIMBAD database for following analysis.

For some PASTEL stars that contain multiple measurements, we removed the very old (eg. published before 1990) measurements that do not consist well with the other ones of the same star, then we adopted the mean value of the remaining measurements. For DR1 stars we remained every multiple measurements available in the catalogs. For each DR1 measurements belong to the same star, we adopted the same adopted stellar parameters of the counterpart in PASTEL as testing standard. We found some of DR1 stellar parameters show great deviation from their testing standard. We selected these potential outliers by $|T_{\rm eff}{}_{\rm DR1} - T_{\rm eff}{}_{\rm PASTEL}| \geq 1000\,{\rm K}$, $|\log g_{\rm DR1} - \log g_{\rm PASTEL}| \geq 0.5\,{\rm dex}$, $|[{\rm Fe/H}]_{\rm DR1} - [{\rm Fe/H}]_{\rm PASTEL}| \geq 0.5\,{\rm dex}$ or $|V_{\rm R}{}_{\rm DR1} - V_{\rm R}{}_{\rm PASTEL}| \geq 20\,{\rm km\,s^{-1}}$. We retrieved DR1 spectra of these potential outliers and checked them one by one. We found some spectra of these potential outliers might have caused problems in determination of stellar parameters. Spectra with low S/N (eg. ${\rm S/N} < 7$) yield poor estimates of stellar parameters. Some spectra with masks leave little information available for stellar parameters determination. Results from such kind of spectra are not reliable. In addition to quality of spectra, we examined the validity of cross-identification of these potential outliers. We found some stars residing in binaries or clusters risky of causing fiber pointing error. That might lead to dramatic change of stellar parameters. We also discovered a few errors in the PASTEL catalog by checking the original bibliographies. They have mistook stellar parameters of KIC 5524720 for those of TYC 3125-2594-1, stellar parameters of TYC 2667-624-1 for those of TYC 2267-624-1 and stellar parameters of SAO 201781 for those of HD 201781. Finally we removed these outliers that satisfy the situations we mentioned above.

Removal of results from problematic spectra enables us to investigate how hot stars affect our comparison results. We grouped multiple measurements from DR1 into different effective temperature bins: $T_{\rm eff} < 8000\,{\rm K}$, $8000\,{\rm K} \leq T_{\rm eff} < 10000\,{\rm K}$ and $T_{\rm eff} \geq 10000\,{\rm K}$. In order to avoid ambiguity, we used different grouping strategy for different bins; we grouped DR1 measurements into the $T_{\rm eff} < 8000\,{\rm K}$ bin only when both their corresponding PASTEL effective temperatures and DR1 effective temperatures satisfy $T_{\rm eff} < 8000\,{\rm K}$; for the other two bins, we accepted measurements with their corresponding PASTEL effective temperatures or DR1 effective temperatures fall within the temperature ranges. Since there were few measurements in the two high temperature bins, we examined them one by one and claimed that there were no duplicate occurrences in these two bins for every single measurement. We found that most stellar atmospheric parameters from spectra of stars hotter than $8000\,{\rm K}$ show great deviation from the testing standard for $T_{\rm eff}$, $\log g$ and [Fe/H] in Figure 1. But $V_{\rm r}$ measurements in the $8000\,{\rm K} \leq T_{\rm eff} < 10000\,{\rm K}$ bin still show moderate accuracy compared with the SIMBAD radial velocities. Finally we confined our sample to a effective temperature range $T_{\rm eff} < 8000\,{\rm K}$ for $T_{\rm eff}$, $\log g$, $[{\rm Fe/H}]$, and another effective temperature range $T_{\rm eff} < 10000\,{\rm K}$ for $V_{\rm r}$, where $T_{\rm eff}$ here stands for effective temperature of both DR1 and PASTEL.

2.3 Internal Scatter of DR1 Stellar Parameters

Now that we have got a clean sample, it is time to combine the multiple measurements in DR1 catalogs for individual stars. It is not necessary to combine multiple measurements for the whole sample. Therefore we only combined the multiple measurements for DR1 stars with their corresponding testing standards available in the PASTEL catalog and the SIMBAD database. We abandoned measurements with low S/N and bad consistency compared with the other ones belong to the same star, then we adopted the mean value of the remaining ones. Actually there were few low S/N measurements left after we removed those outliers. We plotted distribution of DR1 internal scatter of multiple measurements in Figure 2 by taking the adopted stellar parameters as "ground truth". 154 of 176 multiple measurements of $T_{\rm eff}$ for 73 individual stars are within $\pm 100\,{\rm K}$. 42 of 48 multiple measurements of $\log g$ for 19 individual stars are within $\pm 0.1\,{\rm dex}$. 44

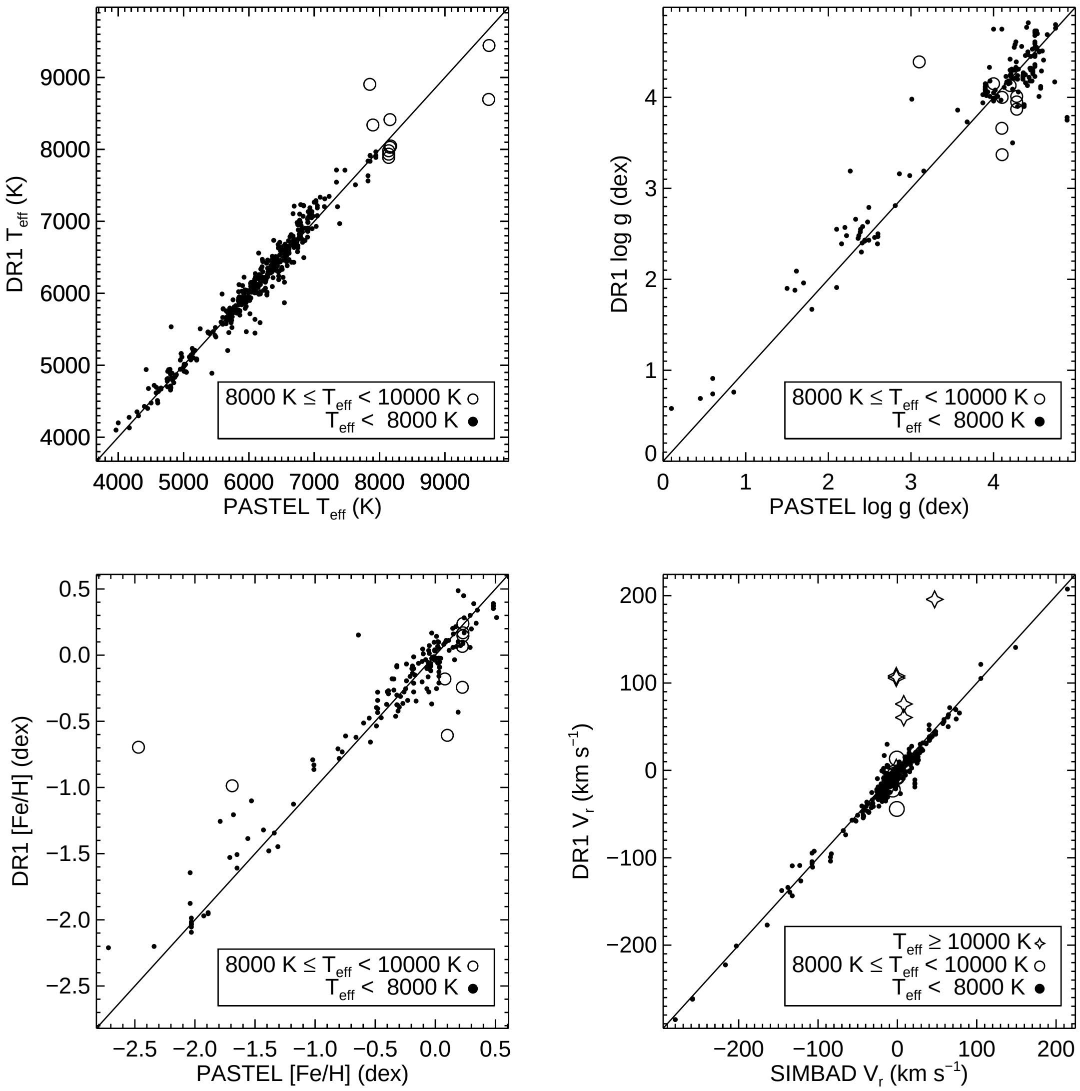

Fig. 1 Test comparison of stellar parameters from DR1 and PASTEL after removal of problematic results. Filled circles indicate measurements in the $T_{\rm eff} < 8000\,{\rm K}$ bin, open circles represent measurements in the $8000\,{\rm K} \leq T_{\rm eff} < 10000\,{\rm K}$ bin and open stars are measurements in the $T_{\rm eff} \geq 10000\,{\rm K}$ bin.

of 48 multiple measurements of $[{\rm Fe/H}]$ for 19 individual stars are within $\pm 0.1\,{\rm dex}$. 151 of 178 multiple measurements of $V_{\rm r}$ for 73 individual stars are within $\pm 5\,{\rm km\,s^{-1}}$. Our adopted stellar parameters seem like reasonable "mean" of multiple measurements because there are few measurements show great deviation from the adopted value.

3 COMPARISON OF STELLAR PARAMETERS

After applying problematic data reduction and reasonable constraint to the sample, we obtained a clean and well-established sample of 306 stars for $T_{\rm eff}$ comparison, 121 stars for $\log g$ comparison, 121 stars for $[{\rm Fe/H}]$ comparison and 277 stars for $V_{\rm r}$ comparison. Figure 3 show the comparison results of the four stellar parameters. Systematic error and dispersion listed in Table 1 were obtained by gaussian fit.

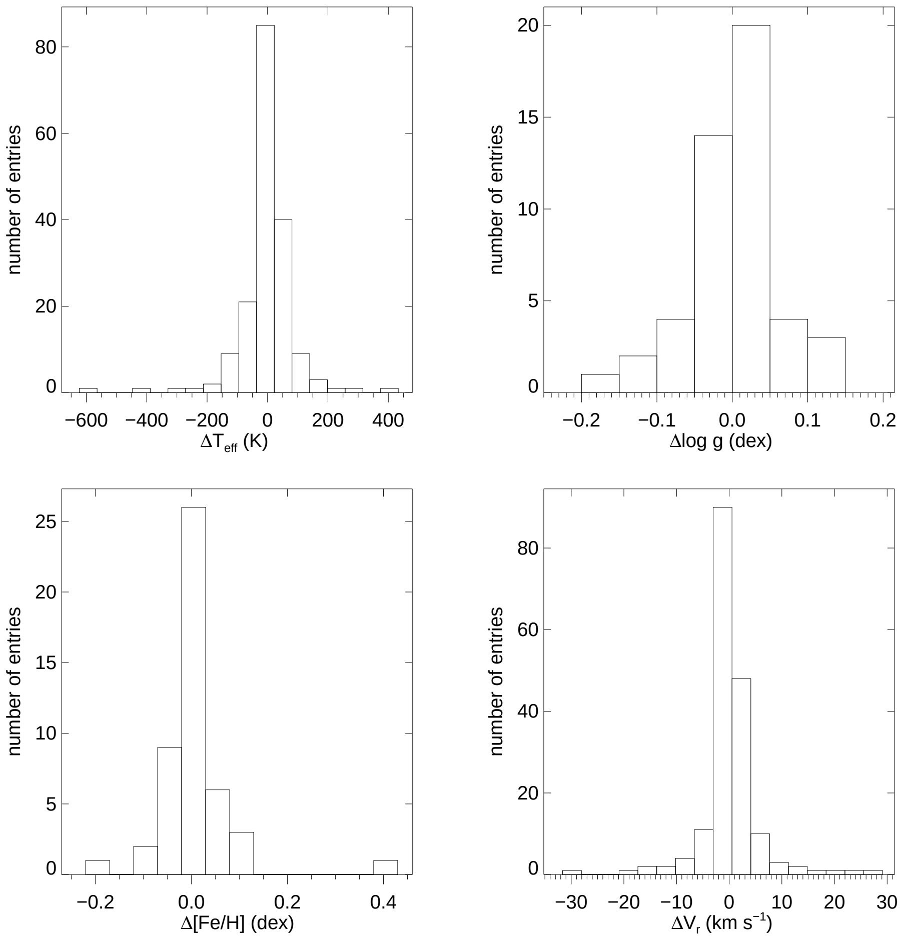

Fig. 2 Internal scatter of DR1 multiple measurements of stellar parameters. Internal scatter of DR1 stellar parameters is defined by $\triangle P = P_{\rm mul} - P_{\rm adop}$, where P is one of the four stellar parameters, "mul" stands for multiple measurements in DR1 and "adop" represents adopted "mean" value of the multiple measurements.

Obviously systematic error of stellar parameters is negligible except for that of $V_{\rm r}$. Since radial velocities in the SIMBAD database are collections from different literatures, biases of different measurements should cancel out; systematic error of $-3.78\,{\rm km\,s^{-1}}$ in the sample should be taken into account when $V_{\rm r}$ being used. We noticed that DR1 metallicities of metal-poor stars (eg. PASTEL $[{\rm Fe/H}] < -1.5\,{\rm dex}$) are systematically higher than metallicities obtained by high resolution spectra analysis. Results from DR7 of the Sloan Digital Sky Survey (SDSS) also show similar behavior due to lack of corresponding calibrators (Xu et al. 2013). One should use caution with using these metallicities. Lee et al. (2008) showed that in a effective temperature range $4500\,{\rm K} \leq T_{\rm eff} \leq 7500\,{\rm K}$, precisions of stellar atmospheric parameters derived by the Sloan Extension for Galactic Exploration and Understanding (SEGUE) Stellar Parameter Pipeline (SSPP) are $141\,{\rm K}$, $0.23\,{\rm dex}$, $0.23\,{\rm dex}$ for $T_{\rm eff}$, $\log g$ and $[{\rm Fe/H}]$ respectively based on comparison with results from high resolution spectra, which is comparable with DR1 dispersion as listed in Table 1. These similarities are not surprising because both SDSS and LAMOST are medium-resolution spectroscopy surveys, and in addition their techniques used to derive stellar parameters share some similarities such as template matching methods.

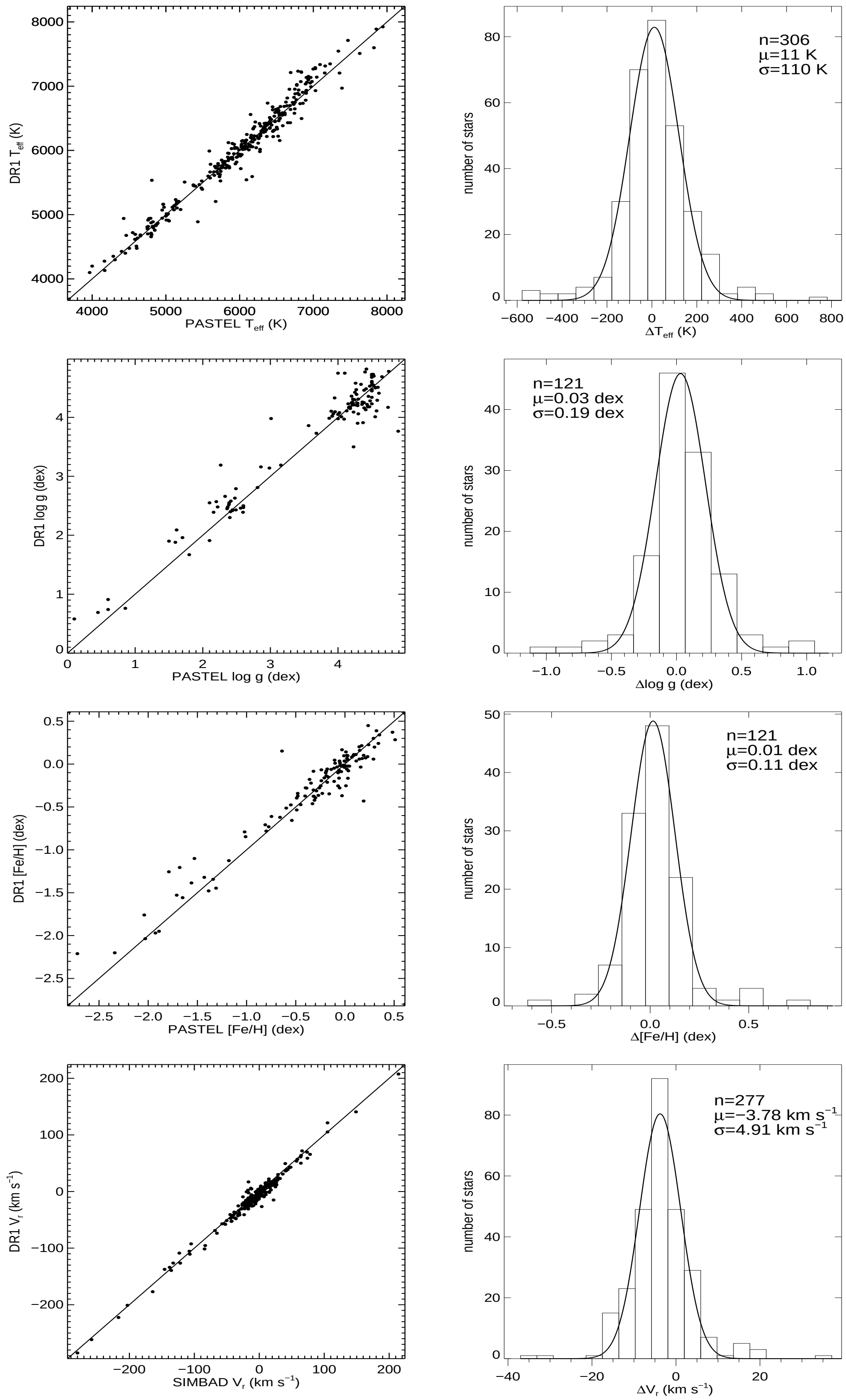

Fig. 3 Comparison of stellar parameters from DR1 and PASTEL combined with SIMBAD database for individual stars in the clean sample. Offset of stellar parameters is defined by $\triangle P = P_{\mathrm{DR1}} - P_{\mathrm{PASTEL}}$, where P is one of the four stellar parameters. In the four figures of the right column, n is number of stars, μ is mean of the gaussian fit, σ is the standard deviation of the gaussian fit.

Table 1 Statistics in Comparison Results of individual stars

	$T_{\rm eff}$ (K)	$\log g$ (dex)	[Fe/H] (dex)	$V_{\rm r}$ ($\rm km\,s^{-1}$)
number of stars	306	121	121	277
systematic error	11	0.03	0.01	-3.78
dispersion	110	0.19	0.11	4.91

4 SUMMARY

We performed cross-identification of the DR1 catalogs and the PASTEL catalog by setting a search radius of 10 arcsec to avoid missing the bright stars with position offset. Then we removed false results and obtained a sample of 422 stars. With this sample we performed a test-comparison and selected some potential outliers for inspection. Finally we removed results from problematic spectra, risky cross-identifications and a few errors in the PASTEL catalog. We obtained a effective temperature range $T_{\rm eff} < 8000\,{\rm K}$ for validation of $T_{\rm eff}$, $\log g$, $[{\rm Fe/H}]$, and another effective temperature range $T_{\rm eff} < 10000\,{\rm K}$ for validation of $V_{\rm r}$, because we did not expect DR1 results hold for all effective temperature ranges. We derived dispersion of 110 K, 0.19 dex, 0.11 dex and 4.91 $\rm km\,s^{-1}$ in specified effective temperature ranges for $T_{\rm eff}$, $\log g$, $[{\rm Fe/H}]$ and $V_{\rm r}$ respectively. DR1 data show systematic error of $-3.78\,{\rm km\,s^{-1}}$ in $V_{\rm r}$ and overestimates of $[{\rm Fe/H}]$ at the low metallicity tail. We are looking forward to more observations of PASTEL stars by LAMOST in the future, which provide us a larger sample to test the LAMOST results.

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