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DETERMINATION OF HOMOGENIZED EFFECTIVE TEMPERATURES FROM STELLAR CATALOGS

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Abstract. Some selected catalogs of the effective temperatures ($T_{\rm eff}$) for F, G and K stars are analyzed. By an improved technique we estimate the external errors of these catalogs from data intercomparisons. The $T_{\rm eff}$ values are then averaged with the appropriate weights to produce a mean homogeneous catalog based on the selected data. This catalog, containing 800 stars, is compared with some other independent catalogs for estimating their external errors. The data may be used as a source of reliable homogeneous values of $T_{\rm eff}$, together with their errors.

Key words: catalogs – stars: fundamental parameters: effective temperatures

1. INTRODUCTION

Many published stellar catalogs are available which contain the main astrophysical parameters of stars ($T_{\rm eff}$, $\log g$, [Fe/H]), and these data are in use for investigations of the Galaxy structure, its star formation and history of chemical enrichment. Such catalogs are based on the various observational data obtained by different methods. Evidently, the errors of astrophysical parameters in various catalogs (sometimes in the same catalog) are different and frequently are known with insufficient accuracy. However, for application of the catalog data, as well as for creation of the weighted compiled catalogs, we need reliable errors. As it was noted in a recent paper of Soubiran et al. (2010), serious efforts should be undertaken to create extensive and homogeneous catalogs of $T_{\rm eff}$, $\log g$ and [Fe/H] covering the whole HR diagram and metallicity range. Such homogeneous catalogs of reliable astrophysical parameters can be also used to select lists of stars applicable for the data calibration in spectral or photometric surveys in the Galaxy.

Compiling the catalogs of stellar parameters, the authors usually begin with reducing all the data sources to a system of one reference catalog, however, next steps in many cases are different. In two recent papers Taylor (2005) and Borkova & Marsakov (2005) have produced large compiled catalogs of the published [Fe/H] values. In both cases similar approaches have been used: the resulting mean [Fe/H] values were obtained by averaging the data with weights derived from the residuals. Such a procedure may be effective only in the case when three or more values of the parameter for the same star are available.

For the catalogs with stars in common, Cenarro et al. (2007) have calculated the variances of data differences with the reference catalog what allows to assign some weights to each catalog and to compile the weighted data for $T_{\rm eff}$, $\log g$ and [Fe/H]. However some involved catalogs may be heterogeneous in accuracy, and this approach does not allow to estimate the external errors for individual catalogs which are important for many applications. Fortunately, when the error of one of the selected catalogs is known, the external error of another homogeneous independent catalog may be estimated from the data intercomparisons, and this approach has been used by some authors (see, e.g., Ducourant et al. 2006 for proper motions).

More productive approaches may be used when triples of homogeneous catalogs with the stars in common are taken together and the external errors of some catalogs are estimated from the data intercomparisons (some early examples of such approach may be found in Chun & Freeman (1978) for B,V photometry and in Evans et al. (2002) for proper motions). In this approach, Malyuto (1994) has applied a special technique for metallicities, where in every triple of catalogs some appropriate weights are assigned to variances of data differences in each pair of the catalogs (for the stars in common to all three catalogs, and for the stars in common only to two catalogs, separately). In our Paper I (Malyuto & Shvelidze 2008) this technique was used to estimate the external errors of $T_{\rm eff}$ for five independent catalogs where all possible triples were considered.

In the present paper we re-analyze the data from the same five catalogs but with the use of an improved technique, which determines external errors of the catalogs by solving linear equations (with variances of the data differences as the function of errors) by the least squares, when the number of catalogs with the stars in common exceeds three. We also define some new improved homogeneous subsamples in these catalogs and estimate their external errors from pairs assuming that the error of one considered catalog in every pair is already obtained as described above. Then trying to produce the mean homogenized catalog we average the values of $T_{\rm eff}$ for every star from two or more catalogs with the weights which are inversely proportional to the squared errors. Possible extension of this catalog with the use of some additional data is discussed.

2. GENERAL PRINCIPLES USED IN THE COMPILING OF CATALOGS

Let X_i denote a quantity in the i-th catalog (measured without bias). If we like to obtain a good estimate of the quantity being measured, we should consider weights, w_i, in the following sum:

$$w_1 X_1 + ... + w_n X_n, i = 1, 2, ..., n,$$

where n is the number of used catalogs. A simple statistical analysis as described in textbooks shows that the weights should be chosen to be inversely proportional to the errors squared:

$$w_1 = \frac{1}{{\sigma_1}^2} \qquad ... \qquad w_n = \frac{1}{{\sigma_n}^2}. \tag{1}$$

Then a good estimate of the quantity (weighted mean) is

$$\overline{X} = \frac{\sum X_i w_i}{\sum w_i}. \tag{2}$$

A standard error of the weighted mean is equal to

$$\sigma_{\overline{X}} = \sqrt{\frac{1}{\sum w_i}}. \tag{3}$$

In the case of catalogs of stellar astrophysical parameters, many published errors σ are unknown or uncertain. Therefore a direct simple approach to averaging the catalogs using their published errors does not prove to be efficient in many cases.

However, there is a possibility to estimate primarily the errors of the catalogs through data intercomparisons (if the used catalogs are homogeneous and statistically independent). Thus we should consider variances of data differences for every pair of the catalogs. Say, for Catalogs 1 and 2 they are:

$$\delta_{12}^2 = \frac{\sum_{j=1}^{N} (X_{1,j} - X_{2,j})^2}{N - 1}, \tag{4}$$

where N is the number of stars in common; other analogous quantities (δ_{13}^2 and so on) should be calculated for all the catalogs. The 3σ rule is applied to the data to reject the stars which may be considered as outliers. From the rule of addition of variances we may write:

$$\delta_{12}^2 = {\sigma_1}^2 + {\sigma_2}^2 \tag{5}$$

$$\delta_{13}^2 = {\sigma_1}^2 + {\sigma_3}^2 \tag{6}$$

$$\delta_{23}^2 = {\sigma_2}^2 + {\sigma_3}^2 \tag{7}$$

for Catalogs 1, 2, 3, etc. If there are three catalogs with some stars in common, the errors may be derived from these variances of the data differences. If there are more than three catalogs with some stars in common, we solve these linear equations by the least squares to derive the errors of the catalogs.

Another possibility to derive the errors is to use only the pairs of catalogs, assuming that the error σ_1 of Catalog 1 (considered as the basic catalog) is known in advance (it might have already been determined using the approach described above for some selected catalogs). Then the errors of Catalogs 2, 3 and so on may be calculated from the appropriate variances of the data differences in the form:

$$\sigma_2^2 = {\delta_{12}}^2 - {\sigma_1}^2 \tag{8}$$

$$\sigma_3^2 = {\delta_{13}}^2 - {\sigma_1}^2 \tag{9}$$

Finally, the obtained errors of the catalogs may be inserted into Eq. (1) to obtain the weights and to produce a mean compiled homogenized catalog of the parameters with the use of these weights in Eqs. (2) and (3).

3. ANALYSIS OF THE SIMULATED CATALOGS

A question may arise, whether the treatment of some catalogs simultaneously (up to five in our case) improves the errors of the catalogs obtained from the data intercomparisons. To verify this, we took some simulated catalogs with the selected σT_{eff} values and considered the results, obtained with the use of our

Table 1. Differences of $\sigma T_{\rm eff}$ (obtained minus given $\sigma T_{\rm eff}$ values) for some combinations of the selected simulated catalogs (the combinations are given in the first column). Triples, quadruples and quintuples of the simulated catalogs are considered.

Given $\sigma T_{\rm eff}$	N=50	N=100	N=200	N=500
30/30/30	-8/7/7	-4/2/2	-4/4/5	1/0/1
30/30/30/30	8/-2/-5/-7	0/-3/5/0	-3/3/2/0	0/2/1/0
30/30/30/30/30	6/-3/-5/-3/5	-1/-4/6/0/1	-2/1/3/0/-2	-1/3/0/-2
50/50/50	-13/11/12	-7/3/4	-6/6/9	0/1/2
50/50/50/50	14/-4/-8/-11	0/-5/8/-1	-5/5/3/-1	0/3/-1/0
50/50/50/50/50	11/-4/-8/-6/9	-1/-6/10/-1/2	-3/1/4/0/-3	-3/1/4/0/-3
70/70/70	-18/16/16	-10/5/5	-8/8/12	3/1/1
70/70/70/70	19/-6/-11/-15	0/0/2/12	-1/5/10/-1	2/2/1/2
70/70/70/70/70	15/-6/-12/-8/12	-2/-9/14/-1/3	-4/2/6/0/-4	-1/2/0/0/-3
50/70/70	-17/17/15	-12/5/5	-13/8/12	2/1/1
50/50/70	-14/11/14	-9/5/4	-9/8/10	2/0/1
30/70/70	-22/18/14	-19/5/5	–/8/12	2/1/1
30/50/70	-14/13/13	-13/5/4	-19/8/11	2/0/1
30/30/70	-10/8/12	-9/6/3	-10/8/9	2/0/2
30/50/50/70	-3/4/15/-8	-1/0/3/6	-1/4/7/0	1/2/0/2
50/60/60/70	8/6/17/-10	0/0/2/9	-1/4/8/-1	1/2/0/2
30/50/50/60/70	12/-7/-11/-4/13	-7/-7/10/0/-2	-8/0/6/1/-2	0/1/0/0/-2
50/50/60/70/70	14/-9/-2/-8/15	-4/-7/12/-1/3	-6/2/6/0/-4	-1/2/0/0/-2

technique, for estimating errors described in the previous Section. The simulated data were produced with random variables drawn from the Gaussian distribution for a given value of $T_{\rm eff}$ = 6000 K and for a given $\sigma T_{\rm eff}$ (30, 50, 60 or 70 K in different combinations), with numbers of stars in common N = 50, 100, 200, 500, respectively. The results are presented in Table 1. Two possibilities were considered: when the given errors in every combination are the same (see the first part of Table) and they are different (the second part of Table).

This Table shows that, in general, the differences become smaller (the results more reliable) with increasing number of stars in common (from 50 to 500), as well as with increasing number of the involved catalogs (from 3 to 5). The differences are the largest when one considerably deviating value is present (say, 30 K/70 K/70 K). For just mentioned combination of catalogs we receive an uncertain result. In the present analysis with real data (see below), the numbers of stars in common are up to several hundreds and exceed 30 for every pair in the compared catalogs.

4. SELECTED CATALOGS

The selected catalogs of F, G and K stars with $T_{\rm eff}$ values are the same as in Paper I, they are presented in the list given below. The catalogs were selected to be independent and as abundant as possible.

1. Catalog 1 of Masana et al. (2006) with 10999 F, G and K dwarfs and giants, values of $T_{\rm eff}$ were obtained using the Spectral Energy Distribution Fit method, the data were taken from 2MASS (JHK_s) photometry, the [Fe/H]) and $\log g$ data are also available (Masana 2008).

2. Catalog 2 (Valenti & Fischer 2005) is a catalog of stellar properties for 1040 nearby F, G and K dwarfs and giants based on fitting of the observed spectral energy distributions and synthetic spectra.

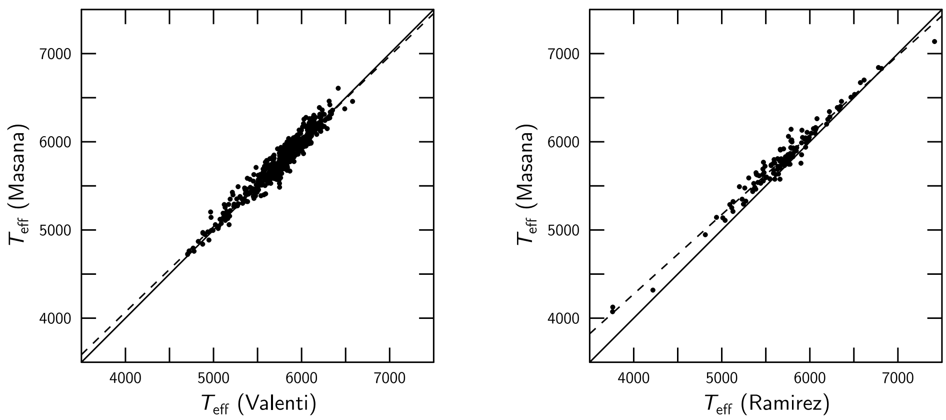

Fig. 1. Comparison of Catalogs 2 (Valenti & Fisher 2005) and 5 (Ramirez & Melendez 2005) with Catalog 1 (Masana et al. 2006). The linear transformation equations (broken lines) were applied for reducing Catalogs 2 and 5 to the system of Catalog 1: $T_{\rm eff}1 = 0.9672 \times T_{\rm eff}2 + 201$ and $T_{\rm eff}1 = 0.9014 \times T_{\rm eff}5 + 668$. The numbers of stars in common are 490 and 125; the correlation coefficients are 0.967 and 0.983, respectively.

3. Catalog 3 (Edvardsson et al. 1993) contains 189 nearby F and G dwarfs with effective temperatures derived from $b - y$ photometry calibrated with a grid of synthetic colors.

4. Catalog 4 (Kovtyukh 2011) contains the determinations of $T_{\rm eff}$ for 647 F, G and K dwarfs and giants from the line depth ratios measured in high resolution spectra (collected with the ELODIE spectrometer at the Haute-Provence Observatory) using calibrations from different sources.

5. Catalog 5 of Ramirez & Melendez (2005) for 754 dwarfs and giants in which for determining $T_{\rm eff}$ the Infrared Flux Method (IRFM) has been applied with the use of IR photometry.

Catalog 1, the largest one, is considered as the reference catalog. In Figure 1 of Paper I, we considered the systematic trends of $T_{\rm eff}$ differences between Catalog 1 and other catalogs of this list as a function of three main astrophysical parameters ($T_{\rm eff}$, $\log g$, [Fe/H]). It was shown that the $T_{\rm eff}$ differences are more scattered for cooler stars and for stars with $[{\rm Fe/H}] < -1.1$. To deal with homogeneous data, we decided to use in the present analysis only the stars with the $T_{\rm eff}$ values within 5200–6700 K and $[{\rm Fe/H}] > -1.1$.

In the present paper, the values of $T_{\rm eff}$ from Catalogs 2–5 were compared with the values from Catalog 1 using the stars irrespective of their $T_{\rm eff}$ but only with $[{\rm Fe/H}] > -1.1$ to check if these catalogs show systematic effects. No effects were found for Catalogs 3 and 4, but some small trends are present for Catalogs 2 and 5 (Figure 1). The temperatures from these catalogs were transformed by linear equations to the system of Catalog 1. Only the transformed data are used in the following treatment.

In some considered catalogs (1, 4, 5), individual published errors of $T_{\rm eff}$ values are presented for every star. We must be cautious using these errors because some of them may not be reliable, or they are only internal errors. These published errors, however, may help us confine our analysis to more homogeneous subsamples. The published errors $\sigma T_{\rm eff}$ were plotted versus $T_{\rm eff}$ values in Fig. 2

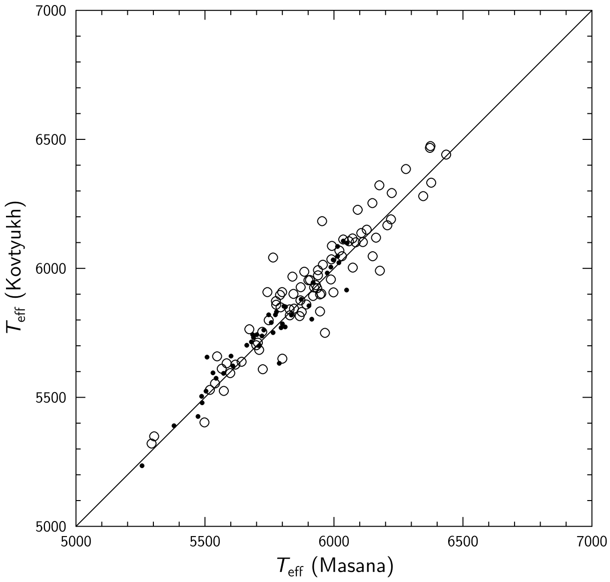

Fig. 2. Comparison of the effective temperatures from Catalog 1 (Masana et al. 2006) and Catalog 4 (Kovtyukh 2011). Only the homogeneous data from Catalog 1 with $\sigma T_{\rm eff} = 40$–60 K, $T_{\rm eff} = 5200$–6700 K and [Fe/H] > –1.1 are plotted. Dots designate the Catalog 4 stars with $\sigma T_{\rm eff} < 5$ K (sample standard deviation $s = 53.9$, $N = 45$) and open circles designate the Catalog 4 stars with $\sigma T_{\rm eff} \geq 5$ K ($s = 82.4$, $N = 81$).

of Paper I. The data are rather scattered and the errors, in general, increase with the temperature. Hoping to deal with homogeneous data, in Paper I we selected the most populated data in some narrow ranges of $\sigma T_{\rm eff}$ as subsamples. Here a question may arise whether the use of a subsample with smaller published $\sigma T_{\rm eff}$ really leads to a smaller scatter in the data intercomparisons. To check this, we present two comparisons below. In Figure 2, two subsamples from Catalog 4 (one with the published $\sigma T_{\rm eff} < 5$ K and another with the published $\sigma T_{\rm eff} \geq 5$ K) are compared with a homogeneous subsample of Catalog 1 explained in the figure. In Figure 3, two subsamples from Catalog 1 (one with the published $\sigma T_{\rm eff} < 50$ K and another with the published $\sigma T_{\rm eff} \geq 50$ K) are compared with a homogeneous subsample of Catalog 4 explained in the figure. In both figures, the data are more scattered when the larger published $\sigma T_{\rm eff}$ values are involved. Therefore, the use of subsamples with the selected ranges of the published $\sigma T_{\rm eff}$ values really helps us in dealing with more homogeneous data in the comparison.

Catalog 2 (Valenti & Fisher 2005) contains the $T_{\rm eff}$ values based on spectral observations (712 stars with only one spectrum and 328 stars with two or more spectra per star), the published error is 44 K for the single-spectrum stars. Thus, Catalog 2 should be not homogeneous with respect to the precision. To verify, in Figure 4 we present the differences of the $T_{\rm eff}$ values between Catalog 1 and Catalog 2 versus the number of used spectra in Catalog 2. The scatter decreases with the increase of the number of used spectra, as expected. Therefore, it would be reasonable to divide Catalog 2 into subsamples according to the number of the used spectra because we wish to deal with homogeneous subsamples.

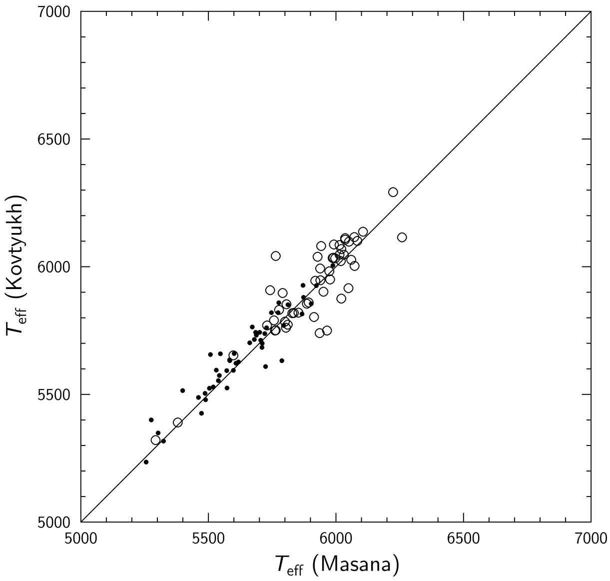

Fig. 3. The same as in Figure 2 but for other subsamples. Only the homogeneous data from Catalog 4 with $\sigma T_{\rm eff} = 2$–7 K, $T_{\rm eff} = 5200$–6700 K and [Fe/H] > –1.1 are plotted. Dots designate the Catalog 1 stars with $\sigma T_{\rm eff} < 50$ K ($s = 56.0$, $N = 58$) and open circles designate the Catalog 1 stars with $\sigma T_{\rm eff} \geq 50$ K ($s = 84.3$, $N = 52$).

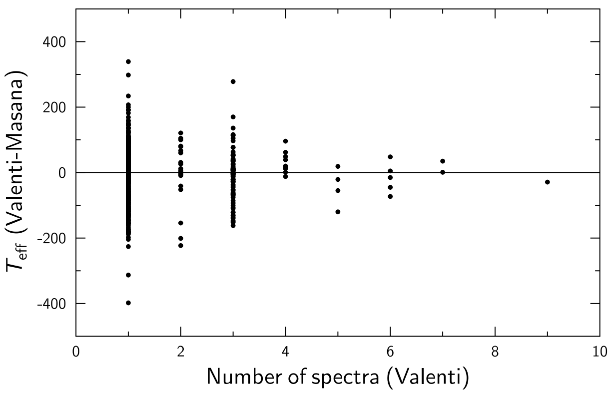

Fig. 4. Differences of the $T_{\rm eff}$ values between Catalog 2 (Valenti & Fisher 2005) and Catalog 1 (Masana et al. 2006) versus the number of the used spectra per star in Catalog 2. The data of Catalog 1 are limited by the following conditions: $T_{\rm eff} = 5200$–6700 K and [Fe/H] > –1.1.

5. ANALYSIS OF THE SELECTED CATALOGS

Judging from the results of Paper 1 and according to our discussion in the previous Section, we have defined the following homogeneous subsamples of the catalogs with $T_{\rm eff} = 5200$–6700 K for further analysis:

1. Subsample 1. From Catalog 1 (Masana et al. 2006) we selected the most populated and homogeneous subsample with $\sigma T_{\rm eff} = 40$–60 K and [Fe/H] > –1.1.

Table 2. External $\sigma T_{\rm eff}$ for the selected seven subsamples from five catalogs.

Combination	Subs. 1	Subs. 2A	Subs. 2B	Subs. 3	Subs. 4A	Subs. 4B	Subs. 5
1-2A-3-4A-5	44	51	-	43	34	-	70
1-2A-3-4A	49	48	-	42	31	-	-
1-2A-3-4A*	50±8	47±10	-	40±9	35±9	-	-
4A-5,2A-5,3-5	-	-	-	-	-	-	72±5
1-2B,2B-4A	-	-	64±10	-	-	-	-
1-4B	-	-	-	-	-	63	-
Final $\sigma T_{\rm eff}$	49	48	64	42	31	63	72
Published $\sigma T_{\rm eff}$	53±5	-	44	25	4.7±1	8.9±1	70±4

* The same data as above but with the use of the technique of Paper I.

2. Subsamples 2A and 2B. From Catalog 2 (Valenti & Fisher 2005) we selected two subsamples: 2A – with two or more spectra per star and 2B – with only one spectrum per star. Only the stars with [Fe/H] > –1.1 are taken.

3. Subsample 3. From Catalog 3 (Edvardsson et al. 1993) a subsample with [Fe/H] > –1.1 is taken.

4. Subsamples 4A and 4B. From Catalog 4 (Kovtyukh 2011) we selected two subsamples: 4A – only with the published errors $\sigma T_{\rm eff} = 2$–7 K and the other (4B) – with the errors 8–12 K. All stars in these subsamples are of normal metallicity (with [Fe/H] > –0.5 where the used calibrations are valid).

5. Subsample 5. From Catalog 5 (Ramirez & Melendez 2005) we selected a subsample with $\sigma T_{\rm eff} = 60$–80 K. Since this catalog does not contain metallicities, [Fe/H] values for this subsample are taken from other catalogs. Subsample 5 is not fully independent of Subsample 1 (some data from 2MASS photometry may be partially used in both subsamples).

We have analyzed each of these subsamples to determine the errors of $T_{\rm eff}$ values through data intercomparisons as described in Section 2. The results are presented in Table 2, where the used combinations of subsamples are given in the first column.

Lines 1 and 2 of Table 2 give the errors determined by use of the combinations of five and four independent subsamples (1-2A-3-4A-5 and 1-2A-3-4A), respectively, by solving linear equations by the least squares. For comparison, the line 3 of Table 2 gives the results for the same subsamples as line 2 but applying a somewhat different technique (used in Paper I). We see that the results in lines 2 and 3 are very similar, and in the following analysis we decided to use only the improved least square technique. As we suspect that the subsamples 1 and 5 are not completely independent (see above), these two subsamples have not been used simultaneously in Table 2, except of line 1.

For the remaining subsamples (2B, 4B and 5) we have determined the errors by processing subsamples in pairs as explained in Section 2 (where one subsample in every pair has already an error estimate from the second line of Table 2). The subsamples are sufficiently populated (minimum there are 32 stars in common in every pair). For two subsamples (2B and 5) there are more than one determination for which the errors of the weighted mean were calculated and presented in Table 2 (with their standard deviations). The next-to-last line of Table 2 contains our final $\sigma T_{\rm eff}$ taken from lines 2 and 4–6. The last line contains the average published $\sigma T_{\rm eff}$ for each subsample, except of the heterogeneous subsample 2A having various

Table 3. A sample from our mean compiled catalog of the temperatures. The involved catalogs are: Cat. 1 – Masana et al. (2006); Cat. 2 – Valenti & Fisher (2005); Cat. 3 – Edvardsson et al. (1993); Cat. 4 – Kovtyukh (2011); Cat. 5 – Ramirez & Melendez (2005). The numbers of the catalogs used (n) and the weighted means of temperatures with their errors are given in the last columns. The full catalog will be available from CDS.

Number	Cat. 1	σ	Cat. 2	σ	Cat. 3	σ	Cat. 4	σ	Cat. 5	σ	n	Wgh. mean
HD 014938	6084	62	–	–	6164	42	–	–	–	–	2	6138 ±34
HD 015335	5977	80	5898	64	5857	42	5950	31	–	–	4	5919 ±22
HD 015632	5728	43	–	–	–	–	5761	31	–	–	2	5749 ±25
HD 016275	5834	46	5848	64	–	–	–	–	–	–	2	5838 ±37
HD 016397	5767	48	5799	64	–	–	–	–	–	–	2	5778 ±38
HD 016417	5880	52	5827	48	–	–	–	–	–	–	2	5851 ±35
HD 016673	6224	60	–	–	6287	42	6292	31	–	–	3	6280 ±23
HD 017037	6189	53	6203	64	–	–	–	–	–	–	2	6194 ±40
HD 023596	–	–	5911	64	–	–	5931	63	6055	73	3	5957 ±38
HD 028005	–	–	5829	64	–	–	5977	31	–	–	2	5948 ±27
HD 030562	–	–	5943	64	5886	42	5836	31	5877	69	4	5866 ±22
HD 030649	–	–	5789	64	5736	42	–	–	–	–	2	5751 ±35
HD 032963	–	–	5775	64	–	–	5741	31	–	–	2	5747 ±27
HD 006434	–	–	–	–	5813	42	–	–	5842	70	2	5820 ±36
HD 010307	–	–	–	–	5898	42	5891	31	5965	73	3	5900 ±23
HD 014214	–	–	–	–	6045	42	6035	31	5977	74	3	6032 ±23
HD 038393	–	–	–	–	6398	42	6388	31	6327	73	3	6384 ±23
HD 041330	–	–	–	–	5917	42	5933	31	–	–	2	5927 ±24
HD 043318	–	–	–	–	6347	42	6340	31	–	–	2	6342 ±24

numbers of the spectra used.

As we can see, our final $\sigma T_{\rm eff}$ for the subsamples 1 and 5 do not significantly differ from the corresponding mean published values given in the last line of Table 2. We may presume that all sources of errors were properly taken into account calculating the published errors of the corresponding catalogs. However, this is not the case for the subsamples 2A, 2B, 3, 4A and 4B, where our final $\sigma T_{\rm eff}$ are significantly larger than the corresponding published values. We may suppose that not all sources of errors have been taken into account in these catalogs. In the case of subsample 3, the authors (Edvardsson et al. 1993) have noted indeed that the published error (25 K) is only due to the errors in the measured b–y values.

6. THE MEAN COMPILED CATALOG

We have produced a mean compiled homogenized catalog of $T_{\rm eff}$ values for stars from the five selected catalogs described above, where we use our estimates of $\sigma T_{\rm eff}$ for defining weights in averaging the data, as explained in Section 2. The compilation of the mean catalog involves the following steps:

1. The data are used only if they are available at a minimum in two catalogs.

2. We consider only the stars with [Fe/H] > –1.1 in Catalogs 1, 2, 3 and 5, with [Fe/H] > –0.5 in Catalog 4, and having $T_{\rm eff}$ = 5200–6700 K in all catalogs.

3. The $T_{\rm eff}$ values are averaged with the weights based on our final $\sigma T_{\rm eff}$ results given in Table 2, but with some modifications. In the case of Catalogs 1 and 5, our final $\sigma T_{\rm eff}$ values for the respective subsamples are similar to the mean published $\sigma T_{\rm eff}$ for these subsamples (see the previous section). It may be reasonable to suppose that such similarity exists for any other subsample of these catalogs. Thus we decided to use the published individual $\sigma T_{\rm eff}$ values for defining the weights for all stars of Catalogs 1 and 5, instead of our final $\sigma T_{\rm eff}$ values.

The mean weighted $T_{\rm eff}$ values and their errors for the stars in the compiled

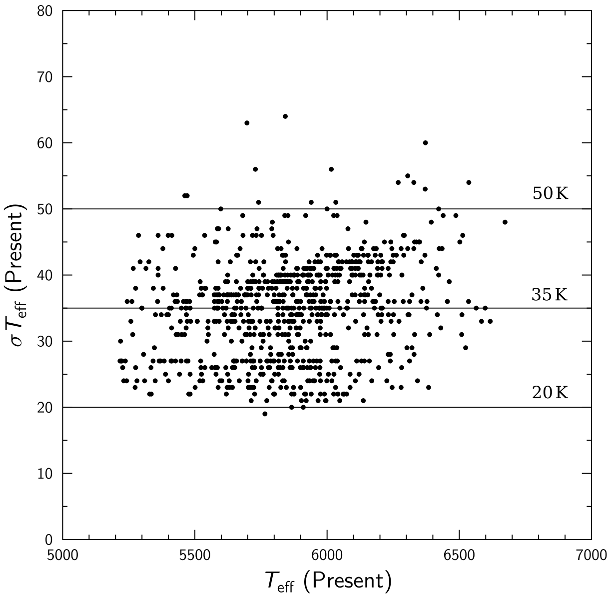

Fig. 5. The $\sigma T_{\rm eff}$ values plotted versus $T_{\rm eff}$, the data are from the present catalog. The homogeneous subsamples A and B with the errors of $T_{\rm eff}$ within the indicated intervals were selected for further analysis. Subsample A: $20 \leq \sigma T_{\rm eff} < 35$ K; mean = 28 ± 4 K; N = 355. Subsample B: $35 \leq \sigma T_{\rm eff} < 50$ K; mean = 40 ± 4 K; N = 429.

catalog were calculated using Eqs. (1)–(3), the total number of stars included is 800.

As an illustration, a sample from the mean temperature catalog is presented in Table 3. In Figure 5, the $T_{\rm eff}$ values of the present catalog are compared with their errors. Two homogeneous subsamples A and B were selected with $\sigma T_{\rm eff}$ between the horizontal lines; the mean values, the standard deviations and the numbers of the subsample stars are given in the figure. These subsamples will be used for analysis of other catalogs in the next section. In Figure 5 a general increase of the errors with $T_{\rm eff}$ may be noted, it is a typical feature of all considered catalogs. The mean errors of $T_{\rm eff}$ values in our mean catalog are significantly smaller than the corresponding individual errors given in Table 3.

7. ERROR ESTIMATES OF THE EFFECTIVE TEMPERATURES IN INDEPENDENT CATALOGS WITH THE USE OF THE PRESENT DATA

Two extensive homogeneous subsamples A and B defined in Figure 5, having the reliable mean external errors of $T_{\rm eff}$ (28 K and 40 K, respectively) may be used to estimate the external errors of the effective temperatures in some other independent catalogs from the variances of the data differences (see Eqs. (8) and (9)). Some examples of such approach are given below.

7.1. The catalog GCS III

A magnitude complete sample of 16 682 F–G dwarfs in the solar vicinity was presented and analyzed in the Geneva-Copenhagen survey (GCS III catalog, Holm-

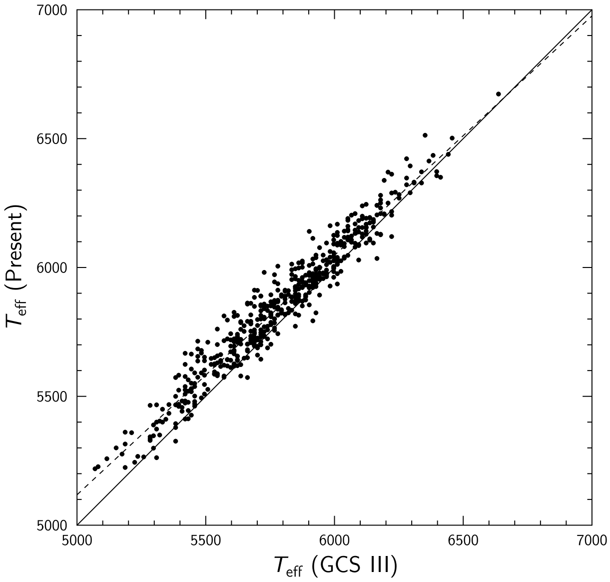

Fig. 6. Comparison of the effective temperatures between the GCS III catalog (Holmberg et al. 2009) and the present catalog. The transformation equation (broken line) is $T_{\rm eff} = 0.9293 \times T_{\rm eff}$ (GCS III) + 471. The number of stars in common is 532; the correlation coefficient is 0.971.

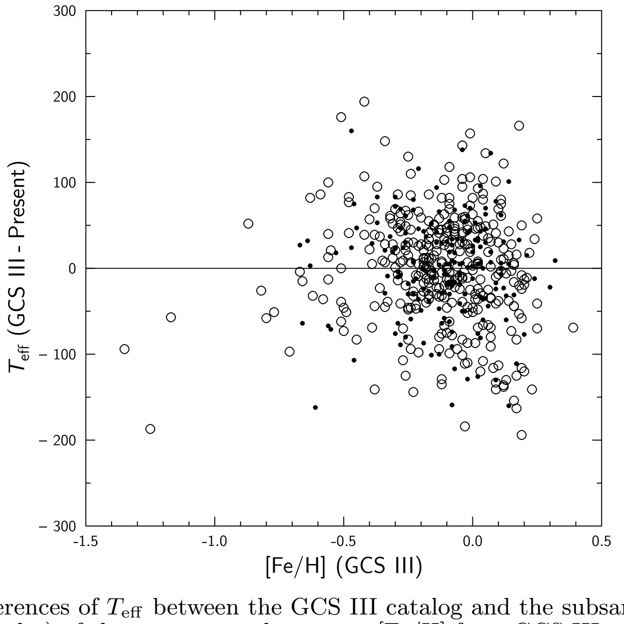

Fig. 7. Differences of $T_{\rm eff}$ between the GCS III catalog and the subsamples A (dots) and B (open circles) of the present catalog versus [Fe/H] from GCS III.

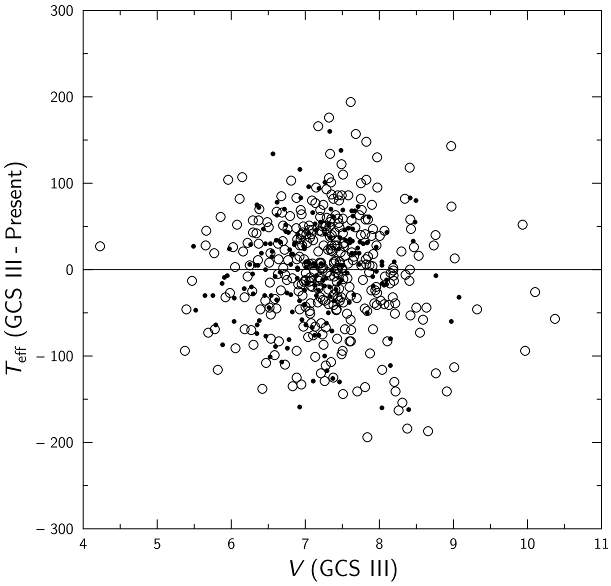

Fig. 8. Differences of $T_{\rm eff}$ between the GCS III catalog and our subsamples A and B versus V magnitude from GCS III. Designations are the same as in Figure 7.

berg et al. 2009), where the $T_{\rm eff}$ (as well as some other parameters) values were derived from photometry in the Strömgren system with the use of recent calibrations. The GCS III catalog does not contain errors of the given temperatures, although these errors may be important in many applications, especially for using them as weights in compilation of new catalogs.

Since GCS III and the present catalog contain 130 stars in common, the same photometric data could be used in both catalogs. To provide the use of only independent measurements, we modified GCS III catalog by excluding the mentioned 130 stars from consideration. One more modification of the GCS III catalog was the reduction of its temperatures to the system of the present catalog by a linear equation (Figure 6). Below we will consider only this modified GCS III catalog.

First, we analyzed possible systematic trends of $T_{\rm eff}$ differences between the GCS III Catalog and the subsamples A and B of the present catalog with some physical parameters. Figure 7 shows that there is no any trend of these differences with [Fe/H], at least for [Fe/H] > -1.1.

Because a magnitude-complete sample of stars in the GCS III catalog is used, we may suspect that the $T_{\rm eff}$ differences depend on magnitude. In Figure 8 the $T_{\rm eff}$ differences (GCS III minus the present catalog) are plotted against V magnitudes taken from GCS III (reddening effects on V are small and can be neglected). We see that the less reliable data for the stars of our subsample B are more scattered, as expected. We see also that the scatter for both subsamples increases with V due to lower accuracy of the GCS III data for fainter stars.

To deal with more homogeneous data, we divided the GCS III catalog into two groups: Group 1 with $V < 7.0$ and Group 2 with $V \geq 7.0$. Then we calculated the variances of the $T_{\rm eff}$ differences (GCS III minus the present catalog) for the stars in these groups (as well as for data with all V) for the subsamples A and B.

Table 4. Determination of the external $\sigma T_{\rm eff}$ for some groups of the GCS III catalog through their intercomparisons with the subsamples A and B of the present catalog.

Group 1 of GCS III with $V < 7.0$ (mean $V = 6.49$)			
	N	St. deviation	$\sigma T_{\rm eff}$
With subsample A	76	53.0	45 K
With subsample B	97	59.7	44 K
			Weighted mean $\sigma T_{\rm eff} = 44$ K
Group 2 of GCS III with $V \geq 7.0$ (mean $V = 7.64$)			
	N	St. deviation	$\sigma T_{\rm eff}$
With subsample A	101	59.9	53 K
With subsample B	247	67.4	54 K
			Weighted mean $\sigma T_{\rm eff} = 54$ K
The GCS III catalog with all V (mean V=7.26)			
	N	St. deviation	$\sigma T_{\rm eff}$
With subsample A	177	57.0	50 K
With subsample B	344	65.2	52 K
			Weighted mean $\sigma T_{\rm eff} = 51$ K

From these variances, with the use of the external errors of $T_{\rm eff}$ for the subsamples A and B, we calculated the external errors of $T_{\rm eff}$ for every GCS III group. The results are presented in Table 4. We see that the derived errors of $T_{\rm eff}$ are very consistent for every GCS III group, the errors for fainter stars being larger, as expected. The $\sigma T_{\rm eff}$ for the brightest stars (Group 1) from GCS III (44 K for the mean $V = 6.49$) is very similar to our $T_{\rm eff}$ error estimate (42 K) obtained for the catalog of Edvardsson et al. (1993) in Table 2, where independent b–y photometry has been used with the mean $V = 5.79$. We consider that the GCS III catalog may serve as one more data source in producing homogenized compiled catalogs with the use of error estimates from Table 4.

7.2. The Fuhrmann catalog

This sample (Fuhrmann 1998) contains about 50 nearby F and G stars, dwarfs and subgiants of the Galactic disk and halo. Effective temperatures were determined from fits of the synthetic spectra to wings of the Balmer lines. This sample is relatively small but important for our analysis because the used data are completely independent from the present catalog, and the analyzed wings of the Balmer lines are very sensitive to the temperature (Schmidt 1972).

One necessary modification of the Fuhrmann catalog was the reduction of its $T_{\rm eff}$ to the system of the present catalog (Figure 9). Figure 10 shows that the $T_{\rm eff}$ differences (the reduced Fuhrmann catalog minus the present catalog) exhibit no trend with [Fe/H]. The data from the subsample B are more scattered, as expected.

Then we calculated the variances of the same data differences for the sub-

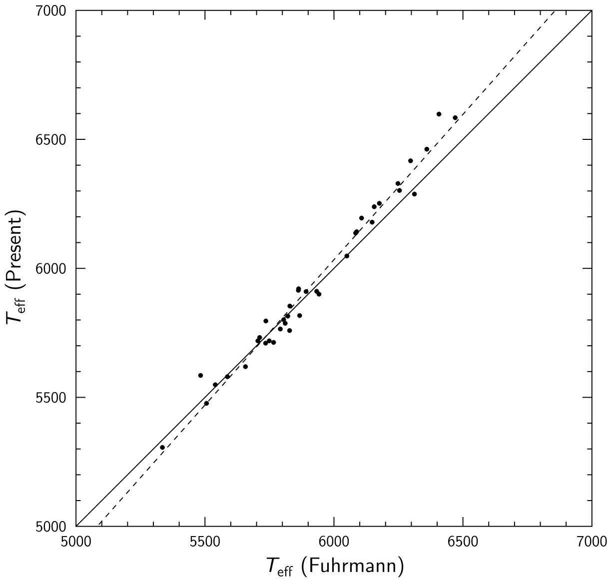

Fig. 9. The same as in Figure 6 but for the Fuhrmann (1998) catalog. The transformation equation (broken line) is $T_{\rm eff} = 1.1266 \times T_{\rm eff}$ (Fuhr) – 726. The numbers of stars in common is 38; the correlation coefficient is 0.989.

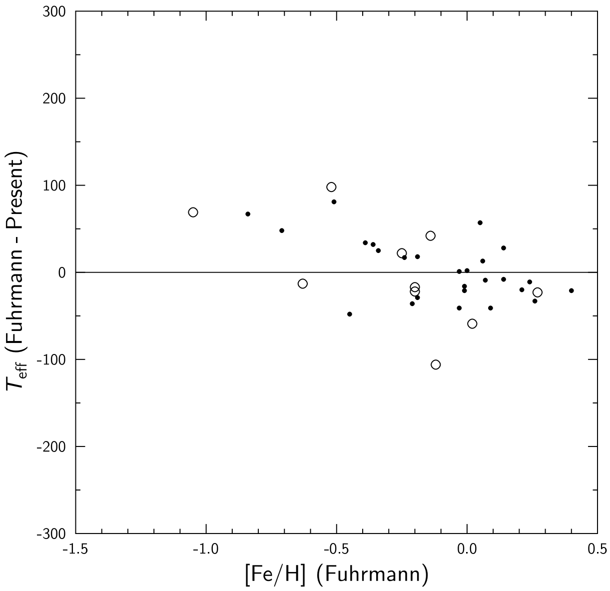

Fig. 10. The same as in Figure 7 but for the Fuhrmann (1998) catalog.

samples A and B: the standard deviations are 35.4 ($N = 26$) and 60.4 ($N = 10$), respectively. From these variances, with the use of the appropriate external errors of $T_{\rm eff}$ for the subsamples A and B, we calculated the external errors of $T_{\rm eff}$ for the Fuhrmann data: 21 K with the use of subsample A and 45 K with the use of subsample B, the weighted average value being 28 K.

Considering the external error estimates of all the catalogs investigated in the present paper (Table 2 and Section 7), we conclude that the lowest errors $\sigma T_{\rm eff}$ are for the Fuhrmann (1998) catalog (28 K) and for subsample 4A of the Kovtyukh (2011) catalog (31 K). For the Edvardsson et al. (1993) and the GCS III catalogs ($V < 7.0$) $\sigma T_{\rm eff}$ are 42 and 44 K, respectively, for the other catalogs they are ~ 50 K or somewhat larger.

8. CONCLUSIONS

We have analyzed some selected catalogs of stellar $T_{\rm eff}$ values, estimated the errors of these catalogs (and/or of some their subsamples) from data intercomparisons, and produced the compiled homogenized catalog based on these data. The present catalog may be used as a source of homogeneous $T_{\rm eff}$ values, together with their errors. The homogeneous subsamples extracted from the present catalog can be used as the comparison data sources for estimating external errors of $T_{\rm eff}$ in other catalogs through the data comparisons. The same approach may be applied also for treatment of other data types (gravities, metallicities, magnitudes, color indices, etc.). In future, we hope to produce more spacious homogeneous samples of stars with reliable astrophysical parameters important for studies of the Galactic structure and evolution, using the observations in large photometric and spectral surveys.

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