Article

Verification of Photometric Parallaxes with Gaia DR2 Data

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Abstract: We present the result of comparison of Gaia DR2 parallaxes and photometry with data derived from a combined analysis of 2MASS, SDSS, GALEX, and UKIDSS surveys in four selected high-latitude sky areas. We have shown that, under certain circumstances, multicolor photometric data from large modern surveys can be successfully used for parameterization of stars, including estimation of distance and interstellar extinction value.

Keywords: parallax; photometry; interstellar extinction; surveys; Gaia

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1. Introduction

Parameters of a star, as well as interstellar extinction, can be obtained from its spectrum. However, to get spectral energy distribution with good dispersion and sufficient accuracy one needs to use large telescope unless the investigated object is bright enough. Another solution of the problem of parameterization of stars is based on their photometry. It was preliminary studied in [1]. A great variety of photometric systems and recently constructed large photometric surveys as well as Virtual Observatory tools for cross-matching their objects provide us with a possibility to get multicolor photometric data for millions of objects. Consequently, it allows user to parameterize objects and determine interstellar extinction in the Galaxy.

The successful implementation of the European astrometric space mission Gaia (the second version of the mission catalog, Gaia DR2, was published in April 2018 [2]) allows us to use its data for solving a number of stellar astronomy problems. In particular, it became possible to verify the results of the parameterization of stars, carried out from multicolor photometry.

In this paper we describe the verification of the method of parameterization of stars with Gaia DR2 data. We also discuss how involvment of Gaia parallaxes into the procedure would improve the accuracy of parameterization, and how to select/process objects for parameterization for which the Gaia parallax is unknown.

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2. Data and method

In Malkov *et al.* [3] (hereinafter — M18) objects in four selected areas in the sky were cross-matched (see details of the procedure in [4], [5], [6]) in 2MASS [7], SDSS [8], GALEX [9], and UKIDSS [10] surveys, and combined photometric data were used to determine the parameters of stars. For 251 objects MK spectral types SpT, distances d and interstellar extinction values A_V were estimated, minimizing the functional

$$\sigma^2 = \sum_{i=1}^{N} \left(\frac{m_{obs,i} - m_{calc,i}}{\Delta m_{obs,i}} \right)^2, \quad (1)$$

where summation goes over up to 13 photometric bands, and

$$m_{calc,i} = M_i(\mathrm{SpT}) + 5\log \mathrm{d} - 5 + \mathrm{A_i}(\mathrm{A_V}), \quad (2)$$

Here $m_{obs,i}$ and $\Delta m_{obs,i}$ are apparent magnitude in i-th photometric band from a survey and its observational error, respectively. $A_i(A_V)$ is the interstellar extinction law, and $M_i(\mathrm{SpT})$ is the absolute magnitude in i-th photometric band taken from calibration tables (see M18 for details).

Then 26 of 251 stars with the most reliable data were selected, and interstellar extinction as a function of distance was constructed for the four selected areas. A comparison with the independent results obtained on the LAMOST [11] telescope for some of the studied stars has demonstrated a good agreement. Also, for three of the four areas, a good agreement was found with the data used in the study of supernovae [12] to confirm the accelerated expansion of the Universe (the issue with the remaining area, No 2, is still open).

To answer the question, posed in Introduction, we relied upon the results obtained in our pilot study of interstellar extinction in four areas (see M18), and Gaia data. We have made a cross-matching of M18 objects with Gaia DR2 catalogue. Among 251 objects, studied in M18, only 72 were found in Gaia DR, one of them has negative Gaia parallax, and seven others have no Gaia parallaxes. Among 26 objects, selected in M18 for construction of $A_V(d)$ relation, one is absent in Gaia DR2, two others have negative parallaxes and two more have no parallaxes.

We compare the Gaia distances (hereafter d_{Gaia}) with ones obtained in M18 (hereafter d). Note that there are other methods for calculating distances from Gaia parallaxes [13], [14], such as the maximum likelihood method, or the Bayesian method, using a priori assumptions about the distribution of stars in the Galaxy. At this stage, however, we restrict ourselves to the simplest estimate, which does not require additional considerations. When analyzing Gaia data, we took into account the recommendations published in [15]. In particular, the filters, designed on the basis of the photometric and astrometric flags contained in Gaia DR2, were taken into account. They were used to construct a so-called atrometrically clean sample, hereafter ACS.

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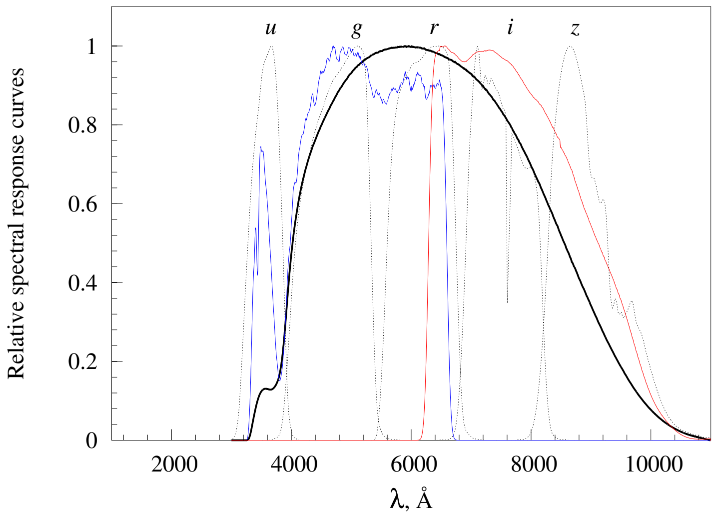

Figure 1. SDSS ugriz (gray dashed curves) and Gaia G (black solid curve), G_{BP} (blue solid curve), and G_{RP} (red solid curve) photometric passbands.

Beside the distances we have also compared SDSS photometric data used in M18 with Gaia photometry. Photometric passbands used in SDSS and Gaia DR2 are presented in Fig. 1. In this work we deal with g_{SDSS} and G_{Gaia} magnitudes (hereafter g and G, respectively) of the studied stars. Comparison of photometric values for the studied stars is shown in Fig. 2.

Objects with Gaia DR2 relative parallax error σ_π/π exceeding 1.3 (see Fig. 3) were removed from the further consideration. There are five such objects in the studied set, and none of them was selected for $A_V(d)$ construction in M18. All of those remaining objects have $\sigma_\pi/\pi < 1.3$. Objects with negative parallax were also removed from the further consideration.

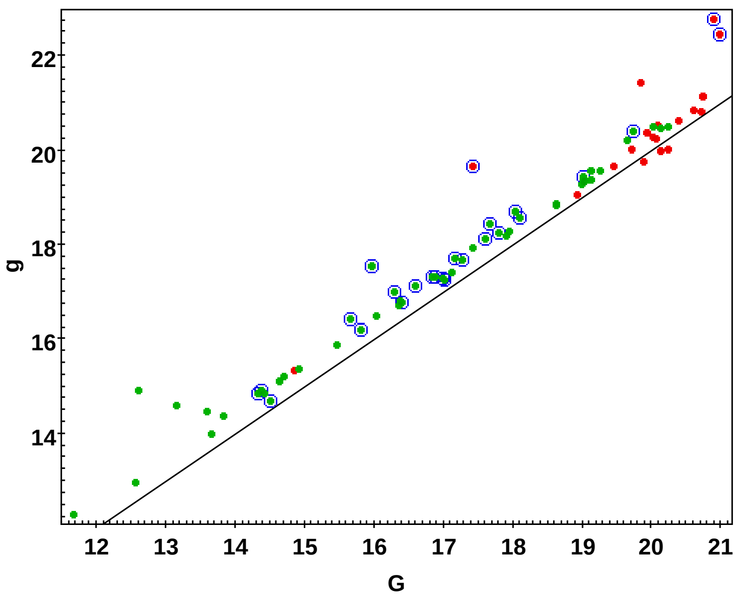

Figure 2. Photometry comparison: g_{SDSS} vs. G_{Gaia} data. "g=G" line is indicated. Red points: all stars parameterized in M18 and found in DR2. Green points: those of red points, which satisfy ACS filters. Blue circles: those of red points, which were used in M18 for $A_V(d)$ construction.

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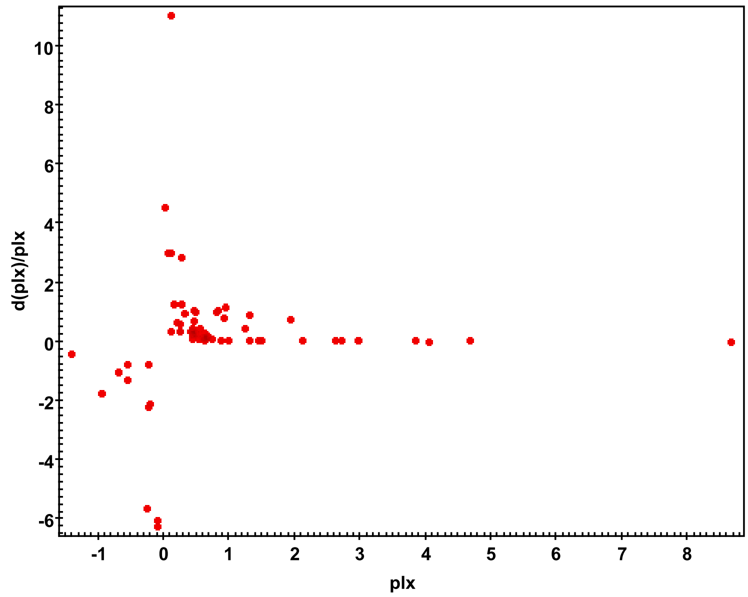

Figure 3. Gaia DR2 parallax vs. relative parallax error distribution. Formal negative parallaxes and errors are also plotted. Objects with relative parallax error exceeding 2.8 and objects with negative parallax were removed from the further consideration.

Concluding this Section we should note that the cross-matching of M18 objects with Gaia DR2 catalogue was made correctly. It can be seen from Figs 4 and 5 that angular distance on the sky between an M18 object and its Gaia DR2 counterpart (ρ) demonstrates correlation neither with differences between Gaia and M18 photometry (i.e., with $g - G$), nor with differences between Gaia and M18 distance (i.e., with $D = d_{Gaia} - d$). Note that two stars with largest angular distance values ($\rho > 0.3$ arcsec) do not satisfy ACS filters and were not selected in M18 for construction of interstellar extinction — distance relation.

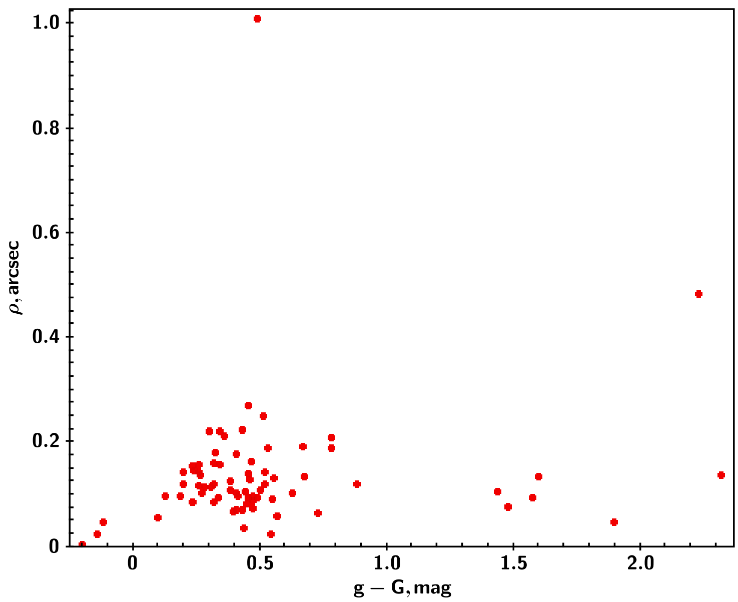

Figure 4. Angular distance on the sky between the star from M18 and its Gaia DR2 counterpart (ρ) vs. differences between Gaia and M18 photometry.

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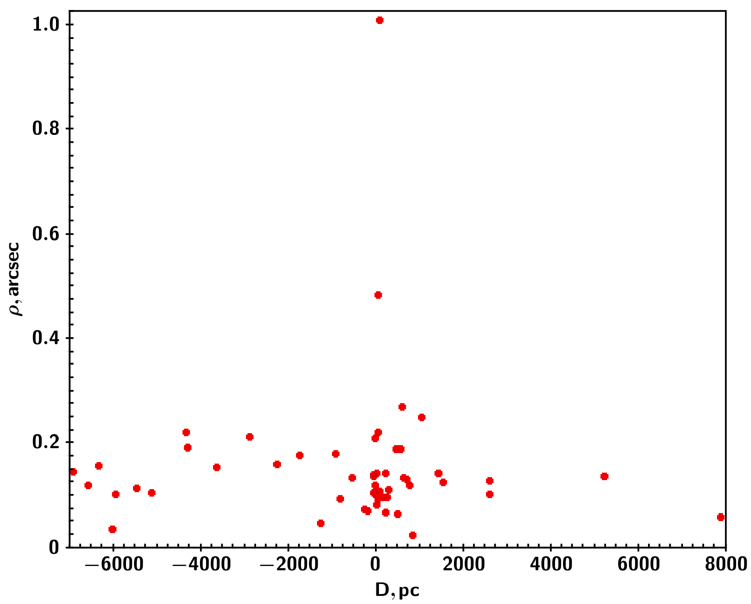

Figure 5. Angular distance on the sky between the star from M18 and its Gaia DR2 counterpart (ρ) vs. differences between Gaia and M18 distance.

3. Results and conclusions

Comparison of distance values for the studied stars is shown in Fig. 6. We also consider distance difference $D = d_{Gaia} - d$ as a function of different parameters.

The results of the comparison allows us to make the following conclusions.

1. Stars with $d > 3200$ pc are badly parameterized (see Fig. 7).
2. Stars with $g > 20.^m3$ of those remaining are badly parameterized (see Fig. 8).
3. For stars that satisfy the criteria 1 and 2 mentioned above, the functional σ value (see 1) should be taken into account. Stars with $\sigma > 49$ pc are badly parameterized (see Fig. 9).
4. Finally, for stars that satisfy the criteria 1 and 2 mentioned above, it is necessary to estimate the probability of their belonging to non-MS luminosity classes. Only MS-stars were parameterized in M18, however a rough estimate of that probability was carried out in M18 (basing on 2MASS and SDSS photometry data). Obviously, for several stars that estimation turned out to be erroneous (see Fig. 10). Consequently it seems very appropriate to include in the parameterization procedure more accurate information about the photometry of giants and supergiants, drawn from the literature or determined by our own efforts.

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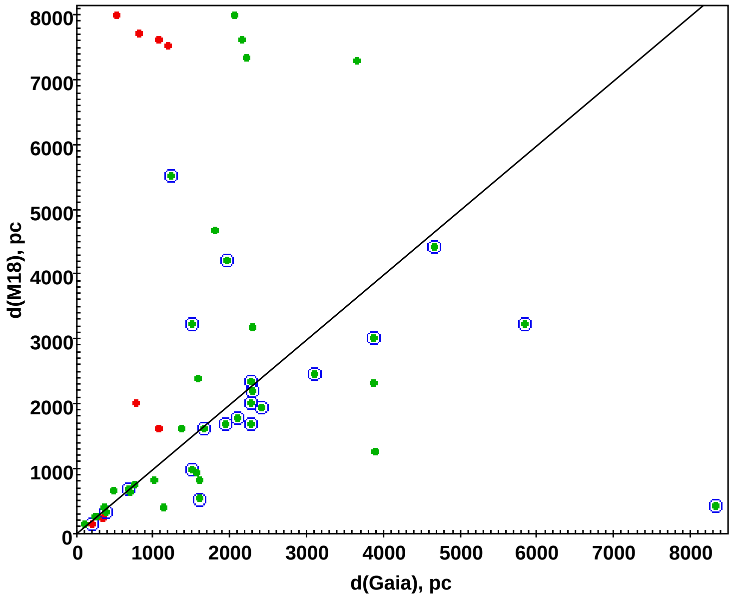

Figure 6. Distance (pc) comparison: d_{M18} vs. d_{Gaia}. "$d_{M18} = d_{Gaia}$" line is indicated. The shape and color of symbols are given in Fig. 2.

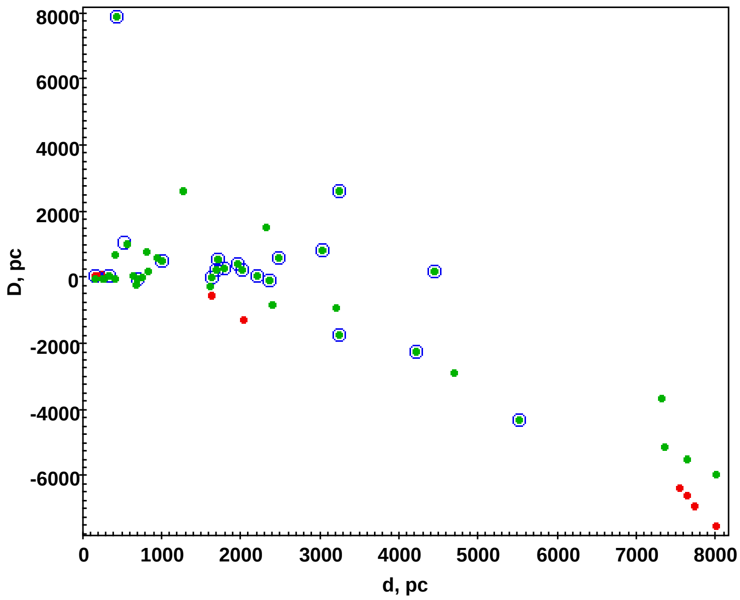

Figure 7. Distance difference D vs. d. The shape and color of symbols are given in Fig. 2.

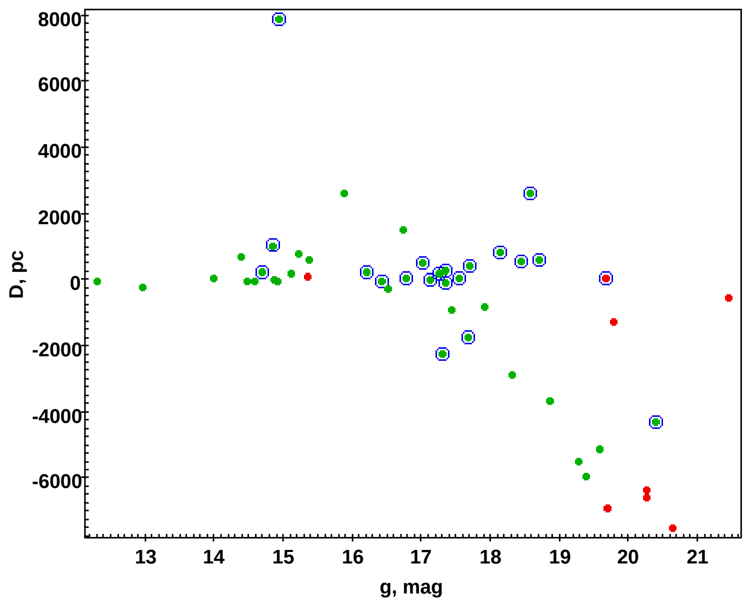

Figure 8. Distance difference D vs. g_{SDSS}. The shape and color of symbols are given in Fig. 2.

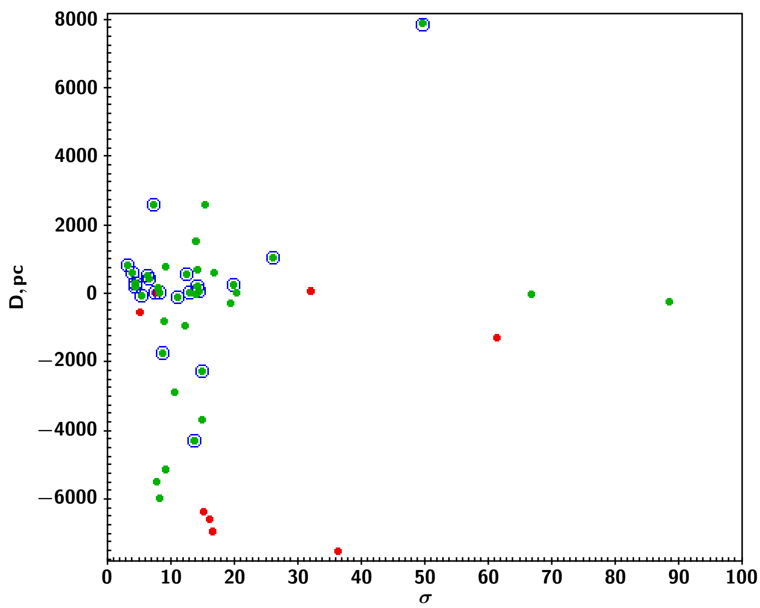

Figure 9. Distance difference D vs. σ (see Eq. 1). The shape and color of symbols are given in Fig. 2.

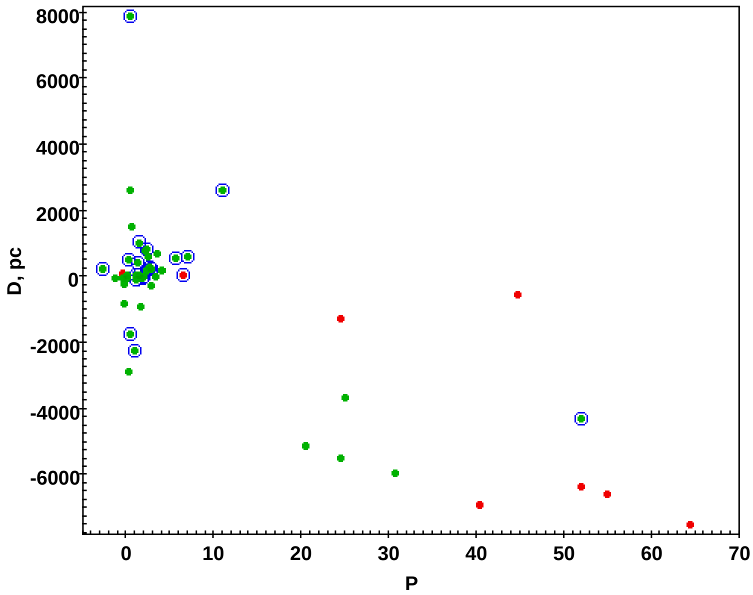

Figure 10. Distance difference D vs. P, which is proportional to a probability for a star to belong to MS. The shape and color of symbols are given in Fig. 2.

We should note also that area No 2, which showed a poor agreement with the Perlmutter et al's [12] data in M18, does not stand out in the current analysis.

Based on the conclusions derived above, we will modify our procedure of parameterization of stars and determination of interstellar extinction. In particular we will extend the procedure to non-MS stars and, on this stage, we will remove from consideration distant ($d > 3200$ pc) and faint ($g_{SDSS} > 20.^m3$) objects. We will also reconstruct the procedure to use Gaia DR2 (and future releases) parallaxes, when available, as an input parameter. We also plan to use data from other multicolor surveys (WISE, DENIS, etc) and extend the procedure application to lower galactic latitudes.

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Conflicts of Interest: The authors declare no conflict of interest.

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