THE PARALLAX ZERO-POINT OF GAIA EARLY DATA RELEASE 3 FROM LAMOST PRIMARY RED CLUMP STARS

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ABSTRACT

We present an independent examination of the parallax zero-point of the Third Gaia Early Data Release (hereafter EDR3), using the LAMOST primary red clump (PRC) stellar sample. A median parallax offset of around 26µas, slightly larger than that found by examination of distant quasars, is found for both the five- and six-parameter solutions in EDR3, based on samples of over 63,000 and 2000 PRC stars, respectively. Similar to the previous investigation of Lindegren et al., to which we compare our results, the parallax zero-point exhibits clear dependencies on the G magnitudes, colors, and positions of the objects. Based on our analysis, the zero-point of the revised parallax can be reduced to a few µas, and some significant patterns, e.g., discontinuities with stellar magnitude, can be properly removed. However, relatively large offsets (>10µas) are still found for the revised parallaxes over different positions on the sky.

1. INTRODUCTION

Based on observations from the first 34 months (from July 2014 to May 2017) from the European Space Agency’s Gaia mission (Gaia Collaboration et al. 2016), the Gaia Early Data Release 3 (EDR3; Gaia Collaboration et al. 2020a) just released astrometric and photometric data for over 1.8 billion sources. Of importance here, five astrometric parameters (position, parallax, and proper motions) are measured for over 81% of these sources (1.468 billion) in EDR3 (Lindegren et al. 2020a). These precisions are improved by 30% for parallaxes, and by a factor of two for proper motions, respectively, when compared to those in Gaia DR2 (Gaia Collaboration et al. 2018).

Investigation of the systematic bias of the measured parallax in EDR3 is very important for its further applications, especially for estimating distances to the more distant stars. The Gaia team has constructed a parallax zero-point model, depending on the G-band magnitude, spectral shape (colors), and ecliptic latitude of the sources (Lindegren et al. 2020b). This model is derived based on a comprehensive analysis of quasars, binary stars, and stellar sources in the Large Magellanic Cloud (LMC). Evaluation of the parallax-bias dependencies for the three independent variables are different for sources with five- and six-parameter solutions. For faint sources, the parallax bias is estimated directly by a large number of quasars covering almost the entire sky (except for the Galactic disk region). However, for brighter sources and also sources with wider color ranges, the parallax bias is derived by an indirect way, based on physical binary stars and stars in the LMC.

In this letter, we perform an independent check on the parallax bias of EDR3 by using over 65,000 primary red clump (PRC) stars (Huang et al. 2020), identified from the LAMOST Galactic surveys (Deng et al. 2012; Liu et al. 2014). This provides an important test of the derived zero-points that need to be used for correction of the EDR3 stellar parallaxes and their application to problems of contemporary interest.

This paper is structured as follows. We introduce the data sources and the method of our analysis in Section 2. In Section 3, we present the results of the parallax zero-point determination. Finally, in Section 4, we present a discussion of our results and conclusions.

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The descriptions of the five- and six-parameter solutions are given by Lindegren et al. (2020b). Briefly, a five-parameter solution is determined if the target has an accurate value of effective wavenumber (ν_eff) to select proper point-spread function (PSF) or line-spread function (LSF) in the data processing pipeline. For six-parameter solution, PSF or LSF at a default ν_eff = 1.43µm−1 is adopted due to no accurate value of ν_eff of the concerned source.

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RESULTS AND DISCUSSION

The comparison between $\omega_{\text{EDR3}}$ and $\omega_{\text{RC}}$ for the five- and six-parameter solutions are shown in Fig. 1. The median offsets are all around $-26\mu$as, slightly larger than the value found from distant quasars (Lindegren et al. 2020b). The parallaxes of EDR3 with zero-point corrections using the model of Lindegren et al. (2020b) are also checked, and the results are shown in Fig. 1. The median values of the parallax difference between $\omega_{\text{EDR3}}$ and $\omega_{\text{RC}}$ are only 4.0 and 1.1 $\mu$as for the five- and six-parameter solutions, respectively. These results confirm that the official parallax zero-point correction model can generally remove the global bias of EDR3 parallaxes.

To further test the main dependencies of the parallax bias in EDR3, Figs. 2 and 3 show the parallax difference between $\omega_{\text{EDR3}}$ and $\omega_{\text{RC}}$, as a function of $G$, effective wavenumber/pseudocolor, and $\sin \beta$ (where $\beta$ represents the ecliptic latitude) for the five- and six-parameter solutions, respectively. Thanks to the large number of PRC stars in the five-parameter solution in EDR3, the parallax-bias dependencies could be mapped in detail. As shown in Fig. 2, significant patterns are found for the EDR3 parallaxes as a function of $G$ magnitude. The discontinuous “jump-like” features found for $10 < G < 11$ and $12 < G < 13$ ranges are similar to those reported in Fabricius et al. (2020) and Lindegren et al. (2020b). This check also shows a positive trend for parallax bias with effective wavenumber, especially at the red end ($\nu_{\text{eff}} < 1.40\mu$m), as also reported in Fabricius et al. (2020) and Lindegren et al. (2020b). For ecliptic latitude, no significant trend is found, except a clear dip feature around $50^\circ < \beta < 70^\circ$. For parallaxes derived from the six-parameter solution, the number of PRC stars is very limited, and most of the fine structures as a function of $G$ magnitude, pseudocolor, and $\sin \beta$ cannot be mapped with high accuracy. We only note that the jump-like features in the parallax bias with $G$ magnitude can still be (marginally) seen.
The dependencies of the corrected EDR3 parallax bias are also checked; the results shown in Figs. 2 and 3 for the five- and six-parameter solutions, respectively. From inspection of Fig. 2, the parallax biases (from the five-parameter solution), as a function of $G$ and effective wavenumber $v_{\text{eff}}$, are considerably reduced by the official zero-point correction model (Lindegren et al. 2020b). Most recently, the independent work by Zinn et al. (2021) has found similar results by using 2000 first-ascent red giant branch stars with asteroseismic parallaxes in the Kepler field. Here, we note that the offset of the parallax difference for $G < 10.8$ and $G > 14.0$ are $9.8 \pm 1.0 \mu$as and $9.0 \pm 0.4 \mu$as, respectively. This implies that the corrected Gaia parallax may over-correct the zero-point at $G < 10.8$ and $G > 14.0$. The over-estimated value of the parallax zero-point by the official Gaia model for $G < 10.8$ found here is similar to the values of $14 \pm 6 \mu$as given by Riess et al. (2020) and $15 \pm 3 \mu$as reported by Zinn et al. (2021). For ecliptic latitude, the dip feature around $50^\circ < \beta < 70^\circ$ is still present. For the six-parameter solution shown in Fig. 3, the pattern of the parallax zero-point discontinuities with $G$ magnitude is largely removed.

In the official parallax zero-point correction model (Lindegren et al. 2020b), the position-dependent bias of EDR3 parallax for bright stars is not well-explored. Here, Fig. 4 shows the 2D position-dependent bias of EDR3 parallaxes (from the five-parameter solution) in ecliptic coordinates. Significant variations ($> 10 \mu$as) over the sky region covered by our PRC sample are clearly seen. To obtain an estimate of the systematic zero-point dependence on positions, the parallax difference between $\omega_{\text{EDR3}}$ and $\omega_{\text{RC}}$, as a function of ecliptic longitude $\lambda$, is shown in Fig. 5. For stars with ecliptic latitude $\beta > 45^\circ$, the median differences for individual $\lambda$ bins exhibit a clear trend, well-described by a one-term Fourier model function (listed in the figure caption). For stars with $30^\circ < \beta < 45^\circ$, the median differences as function of $\lambda$ oscillate around zero with no significant trend. For stars with $\beta < 30^\circ$, the median differences as a function of $\lambda$ oscillate around a positive global offset of $8 \mu$as, again without any systematic trend. Given the similar sky coverage between the LAMOST observations and our PRC sample, we recommend correcting for the position-dependent bias of the EDR3 parallax found here when deriving distances from EDR3 parallaxes for LAMOST stars, and other samples covering similar regions of sky.

4. SUMMARY
Figure 3. Same as Fig. 3, but for the Gaia EDR3 parallax from the six-parameter solution. Note that the central panels here show the parallax difference as a function of pseudocolor, rather than effective wavenumber (see text). The number of stars in each bin is no less than 20.

Figure 4. Map in ecliptic coordinates of the median parallax difference between $\omega_{\text{EDR3}}$ and $\omega_{\text{RC}}$ (left panel), and between $\omega_{\text{Corr EDR3}}$ and $\omega_{\text{RC}}$ (right panel), color-coded as indicated by the top color bars. To clearly show the position-dependent parallax bias, here $\omega_{\text{EDR3}}$ represents the EDR3 parallax after correction for the magnitude dependence detected in Fig. 3 (top-left panel). $\omega_{\text{EDR3}}$ here is given by the five-parameter solution. Each pixel covers an area of about 5 square degrees. The number of stars in each pixel is no less than 15. The solid lines in both panels mark the Galactic plane. The black and grey dots mark the Galactic center and anti-center, respectively.
In this letter, both the EDR3 parallaxes and the revised EDR parallaxes obtained by the official zero-point correction model are checked independently by a sample of LAMOST PRC stars, which are believed to be good standard candles with distance accuracy better than 5 per cent. With over 65,000 PRC stars, the global median offset of EDR3 parallax is found to be around $-26\mu$as for both the five- and six-parameter solutions. The parallax bias in EDR3 exhibits significant systematic trends with $G$ magnitudes, spectral shape (color), and positions. The global offset and the main bias dependencies can be largely reduced by application of the official zero-point correction model. However, the remaining biases in positions still remain, with variation amplitudes larger than $10\mu$as.

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