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Possible large systematic errors of *Gaia* DR2 parallaxes for very bright stars

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The second *Gaia* data release (*Gaia* DR2) with over a billion astrometric parallaxes spanning a magnitude range from $G \sim 3$ to 21 magnitude (Gaia Collaboration et al. 2018a). Here we point out evidence that the parallaxes for the brightest stars ($G \leq 5$) in *Gaia* DR2 may have large systematic errors.

A natural test bed for investigating possible systematic parallax errors are open clusters, provided that the intrinsic dispersion of individual parallaxes is relatively small. Meanwhile, a cluster must be sufficiently nearby to provide bright stars. Among the nearby clusters that satisfy both these conditions the Pleiades is particularly noteworthy. This cluster gained notoriety in space-based astrometry when its Hipparcos-based distance evidenced a much debated discrepancy with other distance determinations. Happily this discrepancy is not present in *Gaia* DR1 (Gaia Collaboration et al. 2017), nor in *Gaia* DR2 (Gaia Collaboration et al. (2018b), hereafter GaiaHRD). However, we note that five of the six brightest stars of the Pleiades in DR2 have significantly larger parallaxes than the rest of the cluster, all of which are consequently missing from the Pleiades' membership list provided in GaiaHRD (their table A.1).

To investigate whether other nearby clusters in GaiaHRD (their table A.2, excluding the Hyades) evidence such systematic parallax difference, stars with $G < 5$ ($G < 5.5$ for NGC 2451) within 5° of the cluster center (10° for Coma Ber) were pulled from *Gaia* DR2, and membership confirmed using the CMD ($G_{\rm BP} - G_{\rm RP}, G$) and the proper motions. We find fifteen bright cluster members: 3 stars in Coma Ber, 3 in α Per, 1 in IC 2391, 5 in IC 2603, and 3 in NGC 2451. Five of these fifteen bright stars are missing from the cluster membership list in GaiaHRD. No stars with $G < 5$ were found in either Blanco I or Praesepe.

We also search for bright Type I Cepheids for which we can find parallax-independent photometric distances, thereby enlarging our sample also to redder objects. In *Gaia* DR2 only a subset of variables are fully characterized, and of these there is only one Type I Cepheid with a mean integrated $G_{int} < 5$, namely X Sgr. Other bright Cepheids are in *Gaia* DR2, but are not classified as such, and their G magnitudes can suffer large errors (see section 5.4 of Gaia Collaboration et al. (2018c)). We therefore cross-matched DR2 with a list of known bright Cepheids (see, e.g., Benedict et al. (2017)), and calculated mean integrated G_{int} and $(G_{BP}-G_{RP})_{int}$ magnitudes from their mean integrated V and I Johnson magnitudes, calculated from the photometry in the literature as cited in Groenewegen (2013) and the periods from Storm et al. (2011), and the color transformations given in Section 5.3.7 of *Gaia* DR2 on-line documentation[1]. In this way we recovered another four bright Cepheids: W Sgr, η Aql, ζ Gem and β Dor. Mean integrated $K_{\rm S}$ and J magnitudes were found, as above, from which we derive their Wesenheit (W) magnitudes ($W = K_{\rm S} - 0.69 \times (J - K_{\rm S})$), and photometric parallaxes from the PW relation given in Inno et al. (2016), whose zero-point has been opportunely calibrated to the recent 1% accurate measurement of the Large Magellanic Cloud distance modulus by Pietrzyński et al. (2019).

In Figure 1 we plot, with respect to G, the difference between the parallaxes of the bright cluster members and their parent cluster (taken from table A.3 in GaiaHRD), and the difference between the DR2 and photometric parallaxes for the Cepheids. Significant differences of up to 2 mas are seen, suggesting large systemic errors, with a possible color dependence at play.

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[1] https://gea.esac.esa.int/archive/documentation/GDR2/Data_processing/chap_cu5pho/sec_cu5pho_calibr/ssec_cu5pho_PhotTransf.html

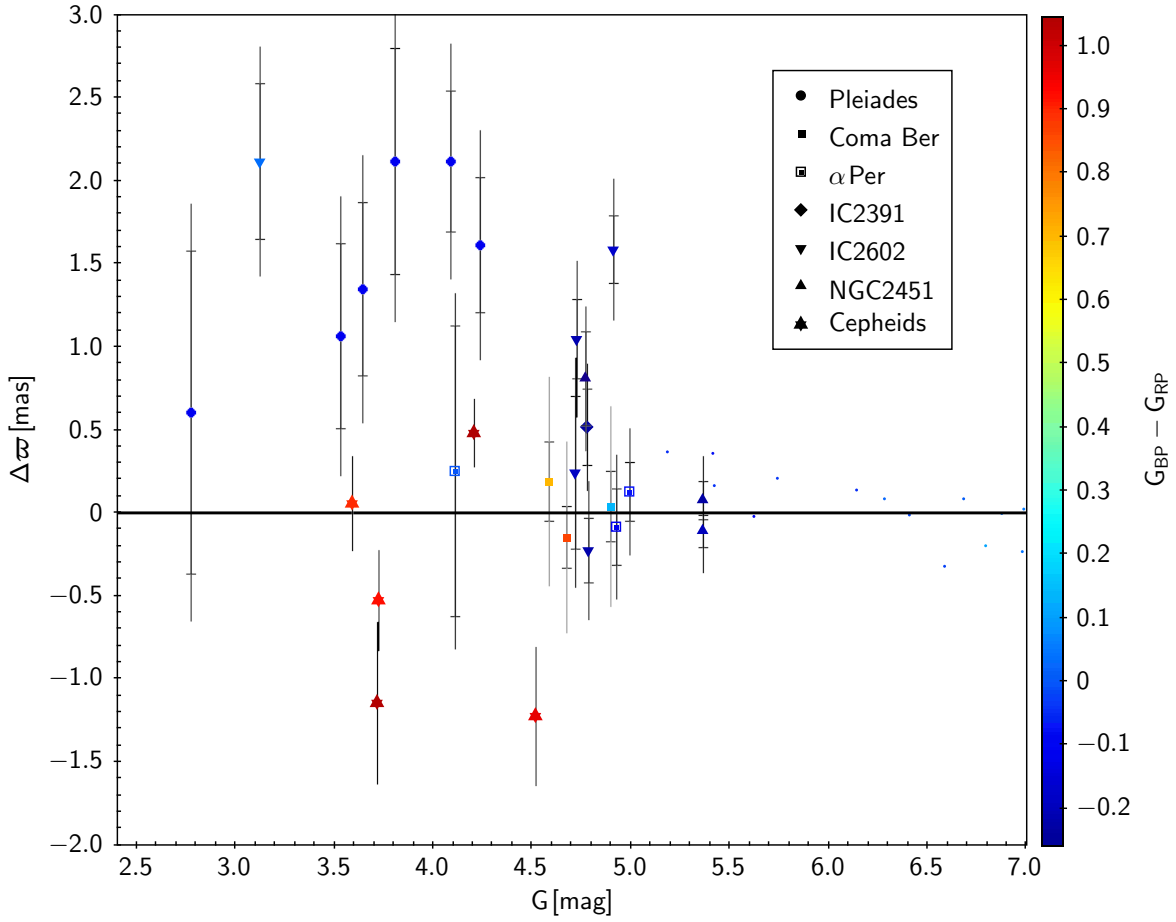

Figure 1. Parallax differences $\Delta\varpi = \varpi_G - \varpi_C$ between *Gaia* DR2 parallaxes ϖ_G and a) the parallax of the parent cluster, for bright members of six nearby clusters, and b) the photometric parallaxes for five bright Cepheids. Small points at $G > 5$ are Pleiades' stars, for comparison. For the bright cluster members, the capped error bars show the uncertainty of their *Gaia* DR2 parallaxes, while the full error bar is with the addition of the standard deviation of the cluster's parallax distribution. Data used are available.

Lindegren et al. (2018) warns that "stars with $G < 6$ generally have inferior astrometry due to calibration issues". *Gaia*'s astrometric measurements depend on self-calibrations that are in part magnitude dependent (e.g. PSF's), which is particularly challenging at bright magnitudes due to the relative scarcity of bright stars. We can however expect an inevitable improvement in future *Gaia* data releases, as additional observations are accumulated.

There are 2136 stars with $G < 5$ in *Gaia* DR2. This note serves to underline the warning cited above by pointing out that, in addition to larger uncertainties, these brightest stars may also have significant systematic errors. Indeed, using the *Gaia* DR2 parallaxes of very bright stars (for instance to determine cluster membership or calibration) should be avoided.

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