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Gaia vs Hipparcos: the Accuracy of Parallax Measurements

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We present a solution for the problem of the discrepancy in the measured trigonometric parallaxes for the stellar binary system HIP 84092. To solve the discrepancy, we used the orbital parameters and our method for analyzing binary and multiple stellar systems (BMSSs)s, described by Al-Wardat in 2002. We used all the available parallax measurements from Gaia DR3, DR2 and Hipparcos-2 in estimating the fundamental parameters of the individual components of the system. Such measurements are usually affected by the orbital motion of the components and the shift of the system photocenter. The masses estimated using the Al-Wardat method along with the modified orbital elements lead to a new dynamical parallax for the system $\pi_{Dyn} = 8.24 \pm 0.15$ mas, which lies in between the measurements of Hipparcos-2 (8.29 ± 0.97 mas) and Gaia DR3 (8.4806 ± 0.4863 mas), while the parallax from Gaia DR2 (20.0561 ± 1.1615 mas) is far from being accurate. This can be explained by the fact that the Gaia telescope has a higher resolution than that of Hipparcos. Based on the fundamental parameters of the binary system components and their positions on the evolutionary tracks, we conclude that the system consists of A7.5 and F1 solar-metalicity main-sequence stars with an age of 0.708 Gyr. Fragmentation is proposed as the most likely scenario for the formation and evolution of the system.

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1. Introduction

In an earlier study of Al-Wardat et al. 2021 [1], which included 1700 stellar systems and focused on the discrepancies in the parallax measurements given in different catalogs including Hipparcos-1, Hipparcos-2, and Gaia DR2, we found that F. van Leeuwen [2] was right in his new reduction of the Hipparcos astrometric data (Hipparcos-2) and his new parallax measurements. We also found in our research that the Hipparcos-2 parallax measurements are closer to those given in Gaia DR3, especially for single stars. That is why we excluded the Hipparcos-1 data from this study.

We revealed that 55 stellar systems in the sample have discrepancies larger than 5 mas between Gaia DR2 and Hipparcos and noted that this difference in the parallax measurements could be due to some issues in the data reduction of the Gaia DR2 observations, a note that was later proved in Gaia DR3, nevertheless with discrepancies still persisting in many cases.

The same study [1] discussed five specific binary stellar systems (BSSs) as an examples of finding a correct parallax. We showed that there are discrepancies between the mass sums calculated or estimated by different methods. The comparison showed that the combination of the Al-Wardat [3] method for analyzing binary and multiple stellar systems (BMSSs) with the dynamical solution is an effective way to solve the discrepancy in the parallax measurements of BMSSs. For more discussion about the parallax discrepancy, please see the analysis of the binary system HIP 16025 [4].

In this study, we focus on the close visual binary system HIP 84092, one of the 55 systems studied in [1]. We aim to resolve the discrepancy in its trigonometric parallax measurements between Gaia and Hipparcos. The key stellar parameter in solving such an issue are the stellar masses. So, we need a complete analysis of the system including its individual masses.

We will compare the dynamical mass sums of the system calculated using different parallaxes with those given by the Al-Wardat [3] method, which barely depends on the parallax. One of the outputs of this method is the estimation of the distance to the target stellar system. It can give a precise parallax if either the system contains stars with well-known spectral types or it has a good orbital solution (Grade 1, 2, or 3 as given by the Sixth Catalog of Orbits of Visual Binary Stars).

2. Analysis of HIP 84092

In 2002, we proposed a new approach to analyze BMSSs [3]. This novel method has been applied to a wide range of binary systems (e.g., [5], [6] [7], [1], [8], [9], and [4]). HIP 84092 is analyzed using our method for the first time in this work. It has been chosen as one of the 55 problematic systems which have been discussed earlier in [1].

The observational data for the system HIP 84092 such as its position (right ascension and declination), magnitudes (visual, blue, color index, and interstellar extinction), and parallaxes are listed in Table (1). There are clear discrepancies in the trigonometric parallaxes between Hipparcos-1 (10.33 mas), Hipparcos-2 (8.29 mas), Gaia DR2 (20.0651 mas), and Gaia DR3 (8.4806 mas). In addition, the system also has a very large value of interstellar extinction.

The Al-Wardat [3] method gives three solutions depending on different parallax measurements. The solutions provide the positions of the binary system components on the H–R diagram and the evolutionary tracks for different masses (see Figure. 1).

Table 1: The observational data for the system HIP 84092: positions, magnitudes, and parallaxes.

Properties	Parameters	Value	Reference
Position	α_{2000}	$17^h11^m29^s.56$	SIMBAD
	δ_{2000}	$-16^o29'30''.80$	SIMBAD
Magnitude [mag]	$m_{\rm v}$	7.51	[10]
	$m_{\rm b}$	7.80	[10]
	$(B-V)_J$	0.287 ±0.011	[10]
	A_V	0.12	[11]
Parallax [mas]	π_{Hip-1}	10.33 ± 1.02	[10]
	π_{Hip-2}	8.29 ± 0.97	[2]
	π_{GDR2}	20.0651 ± 1.1615	[12]
	π_{GDR3}	8.4806 ± 0.4863	[13]

The mass sums estimated by our method are 3.16 $M_\odot$ using the Hipparcos-2 parallax measurements, far below the main sequence using the Gaia DR2 parallaxes (unacceptable solution), and 3.17 $M_\odot$ using the Gaia DR3 measurements.

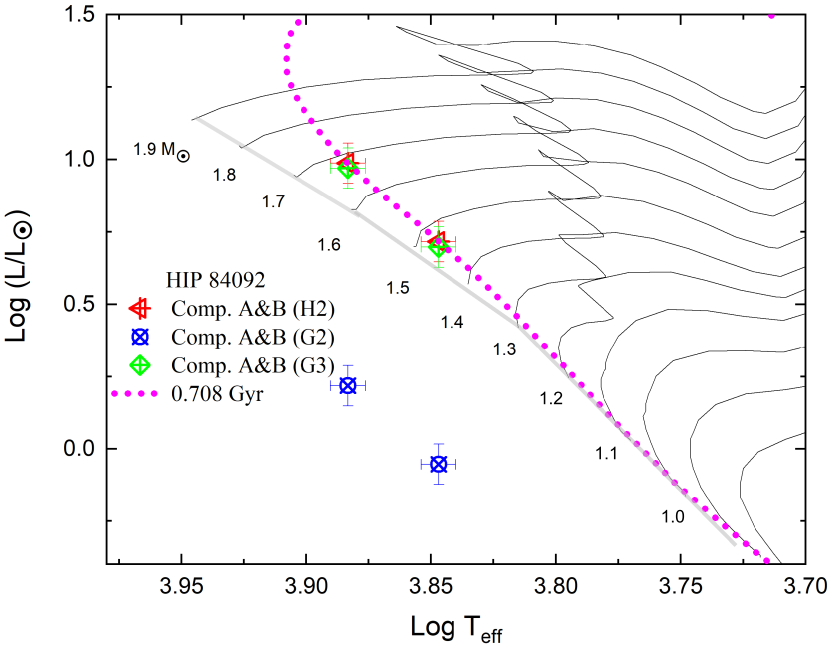

Figure 1: The positions of the HIP 84092 system components on the H–R diagram with evolutionary tracks for solar metallicity. The age line of 0.708 Gyr is shown in pink.

We also calculated the dynamical mass sum using the orbital period P = 79.08 years and semi-major axis a = 0.223 arcsec from Docobo et al. [14] and the formula:

$$\mathcal{M}_{Dyn} = \left(\frac{a}{\pi}\right)^3 \frac{\mathcal{M}_\odot}{P^2}. \quad (1)$$

where P is the orbital period (in years), $\mathcal{M}_{Dyn}$ is the dynamical mass sum in solar masses $\mathcal{M}_{\odot}$, a and π are the semi-major axis and the parallax in arcseconds respectively. The dynamical mass sum is 1.61 $M_{\odot}$ using the Hipparcos-1 parallax measurements, 3.11 $M_{\odot}$ using those of Hipparcos-2, 2.91 $M_{\odot}$ using the Gaia DR3 parallaxes, and 0.22 $M_{\odot}$ using the Gaia DR2 measurements.

Hence, the masses show that the discrepancy in the parallaxes does not significantly affect the masses estimated using the Al-Wardat [3] method, while it does have a clear impact on the dynamical mass sum.

However, having the orbital period, semi-major axis, and masses estimated by the Al-Wardat [3] method, we can estimate a new dynamical parallax using Kepler's third law (Equation 1). The new estimated dynamical parallax is ($\pi_{Dyn} = 8.24 \pm 0.15$ mas), which gives a mass sum of 3.17 $M_{\odot}$.

This dynamical parallax lies between the values given by Hipparcos-2 ($\pi_{(Hip-2)} = 8.29 \pm 0.97$ mas) and Gaia DR3 ($\pi_{(GDR3)} = 8.48 \pm 0.48$ mas) and far from the values given by Gaia DR2 ($\pi_{DR2} = 20.0651 \pm 1.16$ mas). Thus, the results show that the parallax from Gaia DR2 should be disregarded.

Table 2: The adopted final results for the atmospheric and fundamental parameters of the binary system HIP 84092 individual components using the new parallax obtained in this study: $\pi_{Dyn} = 8.24 \pm 0.15$ mas.

		HIP 84092	
Parameters	Units	A	B
$T_{\rm eff} \pm \sigma_{T_{\rm eff}}$	[K]	7642 ± 80	7030 ± 70
$R \pm \sigma_R$	[$R_{\odot}$]	1.745 ± 0.09	1.507 ± 0.08
$\log g \pm \sigma_{\log g}$	[cm/s^2]	4.30 ± 0.11	4.35 ± 0.13
$L \pm \sigma_L$	[$L_{\odot}$]	9.32 ± 0.20	4.98 ± 0.10
$M_{bol} \pm \sigma_{M_{bol}}$	[mag]	2.33 ± 0.08	3.01 ± 0.08
$M_V \pm \sigma_{M_V}$	[mag]	2.33 ± 0.13	3.02 ± 0.14
M	[$M_{\odot}$]	1.69 ± 0.03	1.48 ± 0.04
Sp. Type		A7.5/V	F1/V
Age	[Gyr]	**0.708 GYr**	

The adopted atmospheric and fundamental parameters of the individual system components are listed in Table 2. The parameters are the effective temperatures $T_{\rm eff}$, radii R, gravitational accelerations $\log g$, luminosities L, magnitudes (visual and bolometric), masses, spectral types ($S_{\rm p}$), and age.

The components' positions on the evolutionary tracks and the isochrone reveal that the system consists of two main-sequence stars of classes A7.5 and F1. Such stars with similar fundamental parameters and ages are most likely generated by fragmentation.

3. Conclusion

In this study, we present the solution for the problem of the discrepancy in the trigonometric parallax measurements for the stellar binary system HIP 84092.

To solve the discrepancy, we used a spectrophotometrical technique, the Al-Wardat [3] method for analyzing BMSSs, along with the orbital parameters of [14].

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Based on our analysis, the following main conclusions can be drawn.

- The atmospheric and fundamental parameters of the individual components of the systems have been estimated using a computational spectrophotometrical method, the "Al-Wardat method for analyzing BMSSs" [3].
- The masses estimated by the Al-Wardat method along with the modified orbital elements lead to a new dynamical parallax for the system: $\pi_{Dyn} = 8.24 \pm 0.15$ mas, which lies in between the measurements of Hipparcos-2 (8.29 ± 0.97 mas) and Gaia DR3 (8.4806 ± 0.4863 mas), while the parallax by Gaia DR2 (20.0561 ± 1.1615 mas) is far from being accurate. This can be explained by the fact that the Gaia telescope has a higher resolution than that of Hipparcos. This raises the effect of the influence of the changing binary system photocenter on the parallax measurements, as noted by several authors [15, 16].
- The atmospheric and fundamental parameters of the two components and those of the entire system are listed in Table (2).
- Based on the fundamental parameters of the binary system components and their positions on the evolutionary and age tracks, we conclude that the system consists of A7.5 and F1 solar-metalicity main-sequence stars with an age of 0.708 Gyr.
- For such systems with two very similar components of the same age, fragmentation is proposed as the most likely scenario for the formation and evolution of the system.

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