

REVISED ORBITAL ELEMENTS AND MASSES FOR THE CLOSE BINARY SYSTEM HIP 43630 (HD 75553)

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Abstract: *In this study, the orbital elements of the close visual binary stars system (CVBSs) HIP 43630(HD 75553) are refined; we improved the orbit of this system using new observational data. Positional parameters were derived from speckle interferometry data from previous studies and newly collected data. The calculations were based on an assessment of Gaia Early Data Release 3 and Hipparcos trigonometric parallax measurements, of Visual binary Stars and the Sixth Catalogue of Orbits of Visual Binary Stars Integrating current versions and data of the fourth Catalogue of interferometry measurements, as well as updated information from the Gaia archive and SIMBAD. Tokovinin's dynamical modeling technique for deriving optimal orbits of interferometric binary systems determined the system's orbital elements. Finally, we determined the combined dynamic mass of the system.*

Introduction

Studies have found that binary and multiple star systems are prevalent in the Galaxy, with occurrence rates reaching around 50% among nearby solar-type main-sequence stars [6] and approximately 42% among nearby M-type stars [8]. The majority of stellar systems in our galaxies are categorized as singles, binaries, triples, and higher order hierarchies, marking a significant milestone in the history of astrophysics. Astronomy has improved significantly through the study of binary stars, a valuable source of data on stellar masses, evolutionary models, and stars for motion theories [1, 14]. Determining the origin and evolution of close visible binary systems, as well as the formation and history of the Galaxy in general, requires analyzing their geometric properties, especially their masses.

The Tokovinin dynamical modelling method is used to characterize the orbital elements and kinematic properties of nearly observable binary systems in astronomy [15]. This method is very useful for investigating these kind of systems by least-squares method used to reduce observed and predicted residual relative position information [18]. However, the Sixth Catalog of Orbits of Visual Binary Stars contains a number of solutions, including our system HIP 43630 (HD 75553). So far, about 3655 orbits of visual binaries are included in this catalogue, some with two or more orbital solutions due to recent measurements [3]. The orbits should be used based on the recent observation from Gaia Early Data Release 3, and when new speckle observations of the system are available. The advantage of using the Tokovinin dynamical modelling method can also be used to directly calculate the

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mass of the system associated with different parallax observations, as well as the studying the formation and evolution in the H-R diagram [2]. Detailed studies of the systems have been achieved by emerging techniques such as adaptive optics and speckle interferometry [4, 9]. Previous studies have investigated the application of the Tokovinin dynamical modeling approach to several well-observed binary star systems, where the analysis uses input parameters such as orbital observing epoch, position angle (θ), and angular separation (ρ) was used. The aim of this work is to investigate and modify the orbital elements of HIP 43630 (HD 75553) using a dynamic modelling technique. In addition, we will calculate the dynamic mass with parallax measured values from Hipparcos and Gaia Early Data Release 3 and then revised orbital elements.

Table 1: Basic Parameters and Observed Photometric and Astrometric Data for the System HIP 43630 (HD 75553).

Properties	Elements	Value	Source of data
Position	α_{2000}	$08^h 53^m 08^s$	[5]
	δ_{2000}	$+54^\circ 57' 10''$	[5]
	m_v	7.38	[7]
Magnitudes [mag]	A_v	0.0769	[13]
	$(B - V)_J$	0.619 ± 0.011	[7]
	B_T	8.136 ± 0.010	[10]
	V_T	7.449 ± 0.009	[10]
	$\pi_{Hip\ 1}$	18.23 ± 1.08	[7]
Parallax [mas]	$\pi_{Hip\ 2}$	19.19 ± 0.73	[17]
		19.67848	
	π_{GEDR3}	± 0.173	[9]

Archived Data

Our photometric observations are taken from a variety of sources, including the Hipparcos and tycho Catalogue (ESA, 1997), Hipparcos catalog [17], the Fourth Catalog of Interferometric Measurement of binary Stars (INT4), Sixth Catalog of Orbits of Visual Binary Stars, and Gaia Early Data Release 3 [4]. HIP 43630 (HD 75553, WDS Jo8531+5457AB, and SAO 27027) is classified as a Go spectral type (SIMBAD). the stellar system is located at a right ascension of ($02^h 20^m 51^s$), declination of ($+30^\circ 38' 48''$), and Photometric magnitude in the Optical Visual band between 500 nm and 600nm (7.38^m). The fundamental properties of the HIP 34630 binary system are tabled in Table 1. The system's parallax has been measured by multiple sources, yielding varying estimates. The Hipparcos and Tycho Catalogues report a parallax of 18.23 ± 1.08 mas, corresponding to a distance of 54.85 pc [7]. The Hipparcos reduced catalog provides a parallax of 19.19 ± 0.73 mas, indicating a distance of 52.11 pc [17]. Lastly, Gaia Early Data Release 3 gives a parallax of 19.67848 ± 0.173 mas, corresponding to a distance of 50.82 pc [4].

Method and Analysis

However, the relative motion of the secondary component around the primary component in a binary system requires determining the orbital elements. Consequently, we employ Tokovinin dynamical modelling method to help us in deriving the best orbital elements based on the preliminary values of the system's positional measurements, which are taken from the Fourth Catalog of Interferometric Measurements of Binary Stars, including position angle (θ), and

angular separation (ρ). In addition, the most recent orbital elements provided by Tokovinin et al. (2015) in the Sixth Catalog of Orbits of Visual Binary Stars are used. The best orbital elements for the star system are then calculated by entering these values into the ORBITX program [15]. This is an updated version of Tokovinin's ORBITX program [15]. New speckle interferometric data allow us to determine the system's orbital solution and dynamical star mass. This method accurately computed orbital elements for visual binary and multiple systems, such as [3, 18].

Tokovinin's dynamical analysis technique is utilized to derive the orbital elements, including the period (P) (in years), longitude of periastron (ω) (in degree), time of periastron passage (T) (in years), semi-major axis (a) in (arcsec), eccentricity (e), inclination (i) (in degree), and position angle of the line of nodes (Ω) (in degree), for the stellar system HIP 43630 (HD 75553). It is worth noting that the orbit of the HIP 43630 (HD 75553) systems was previously published by Tokovinin, et al. [16], however, it needs to be updated in light of the new positional parameters [11, 12]. Table 2 presented data from the Fourth Interferometric Catalog, which includes new interferometric measurements for the HIP43630 (HD 75553). While in Figure (1), we explain Tokovinin's dynamical modelling technique and the steps involved in revised orbital elements for CVBSs.

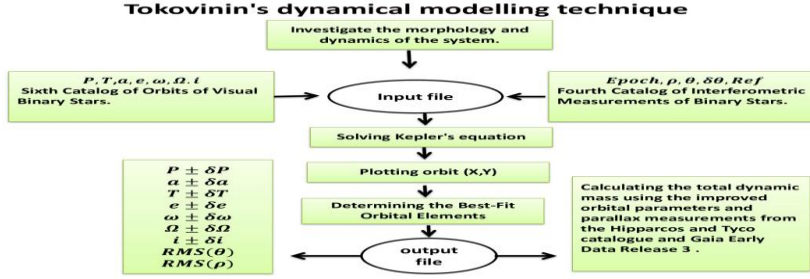


Figure 1: This Figure Demonstrates the Process and Stages Required in Revised Orbital Elements for Cvbss Using Tokovinin's Dynamical Modelling Method.

Orbit Construction and Masses

We apply Tokovinin's dynamical modelling method to refine the apparent orbits of the binary systems HIP 43630 (HD 75553). This study employed new observational data sourced from the Fourth Catalogue of Interferometric Measurements of Binary Stars (INT4), which enabled us to precisely determine the orbital elements of the system. The orbit elements of HIP 43630 (HD 75553) were initially calculated and published by Tokovinin, et al. [16] in the Sixth Catalog of Orbits of Visual Binary Stars. The old orbit used the first 26 pointed measurements before 2014 to construct the orbit see Figure 2 (A). In addition, we recently found an additional two position measurements performed after the epoch 2012 published by Riddle, et al. [12] and Prieur, et al. [11], which enabled us to recalculate the orbit and the orbital parameters using 28 relative positional measurements, as listed in Table 2. Table (2) presents observational data in column 1, and position angle and separation values with standard errors are shown in columns 2, 3, and 5. The observed difference in magnitude between the components, the wavelength used for the observation, The telescope aperture in meters at which the observations were obtained, and the reference to the publication where the measurements were announced are all included in columns 6, 7, 8, 9, and 10, respectively. Column 10 contains the technique used in the observation.

Table 2: Relative Positional Measurements Made with Various Techniques That Are Applied to Construct the System's Orbit HIP 43630 (HD 75553).

Date Epoch	θ	$\Delta\theta$	P	$\Delta\rho$	Δm_v	λnm	Tel.	Meth
1980.885	185.6	1.5	0.231	0.006		550	0.6	Ig
1986.8868	346	.	0.121	.		538	3.8	Sc
1987.269	358.7	.	0.135	.		549	3.8	Sc
1989.2296	31.7	.	0.225	.		549	3.8	Sc
1990.2699	41.1	.	0.269	.		549	3.8	Sc
1991.25	46	.	0.305	.	0.172	511	0.3	Hh
1991.25	.	.	.	.	0.13	505	0.3	Hh
1991.25	.	.	.	.	—	435	0.3	Hh
1991.3267	46.9	.	0.314	.	—	549	3.8	Sc
1991.77	56.3	.	0.33	.	1.27	530	1.4	Ht
1991.77	.	.	.	.		430	1.4	Ht
1991.8944	47.5	.	0.339	.		549	3.8	Sc
1992.2146	51	3	0.352	0.008		600	1.0	S
1993.2025	:	52.1	.	:		549	3.8	Sc
1992.3068	50.4	.	0.351	.		549	3.8	Sc
1993.9259	57.1	.	0.397	.		549	2.5	Sc
1994.2236	:	57.5	.	:		549	2.5	Sc
1996.8638	64.6	.	0.479	.		549	2.5	Sc
2004.1956	76.3	0.7	0.604	0.007		550	1.55	Su
2005.256	78.5	0.8	0.621	0.015		644	1.0	S
2005.8636	78.9	.	0.622	.		550	3.8	Su
2006.278	81	.	0.59	.		560	0.7	Su
2007.192	79.7	1.2	0.652	0.008		644	1.0	S
2008.172	82.3	.	0.641	.		570	0.7	S
2009.139	83.4	0.3	0.627	0.008		644	1.0	S
2012.238	86.1	0.3	0.678	0.015		644	1.0	S
2013.0393*	89.5	0.1	0.678	9E - 4		754	1.5	Ag
2014.196*	89.4	0.5	0.651	0.012		644	1.0	S

Note *: denotes the systems' new positional parameters.

Figure 2(A) The visual orbit of the Hip 43630 system as observed by Tokovinin, et al. [16] and (B) depicts the relative visual orbit of the binary system, with the epoch of the positional data employed to construct the orbit diagram. Figure 3 depicts the updated orbit and serves as a comparison to the previous one publish by (A. Tokovinin et al. [36] (dotted line) and our work (solid line). The calculated new orbital elements of the system are presented in the table (3), The RMS values of the new solution $\Delta\theta = 0.95$ (in degree) and $\Delta\rho = 0.08$ in (in arcsec) are better than those of the previous solution. Table 3 displays the following orbital elements. The dynamical total mass of the system is calculated employing Kepler's third law, utilizing the semi-major axis (a) and orbital period (P) from the derived orbital solution, alongside parallax measurements from the Hipparcos ESA 1997, Hipparcos reduced catalog, or Gaia Early Data Release 3 sources.

$$M_{Dyn} = M_A + M_B = \left(\frac{a}{\pi}\right)^3 \frac{M_{\odot}}{P^2}, (1)$$

and the formal error is given by:

$$\frac{\delta_M}{M_{Dyn}} = \sqrt{9\left(\frac{\delta\pi}{\pi}\right)^2 + 9\left(\frac{\delta a}{a}\right)^2 + 4\left(\frac{\delta P}{P}\right)^2}, (2)$$

Employing the orbital period (P) and semi-major (a) axis derived from the orbital solution, in conjunction with the parallax measurement, Table 4 compares the dynamical masses calculated by Tokovinin et al. [36] and the present work.

Table 3: New Orbital Element Solutions for the HIP 43630 (HD 75553) System Have Been Provided by This Study.

<i>Orbital element</i>	<i>Unit</i>	<i>This work (HIP 43630)</i>
P	[yr]	70.44713 ± 1.16656
T	[yr]	1985.2447 ± 0.0501
e	—	0.7270 ± 0.0057
a	[deg]	0.419 ± 0.0023
Ω	[deg]	243.1 ± 2.42
ω	[yr]	39.5 ± 2.79
i	[arcsec]	33.2 ± 0.92
$RMS(\theta)$	[deg]	0.95
$RMS(\rho)$	[arcsec]	0.0080

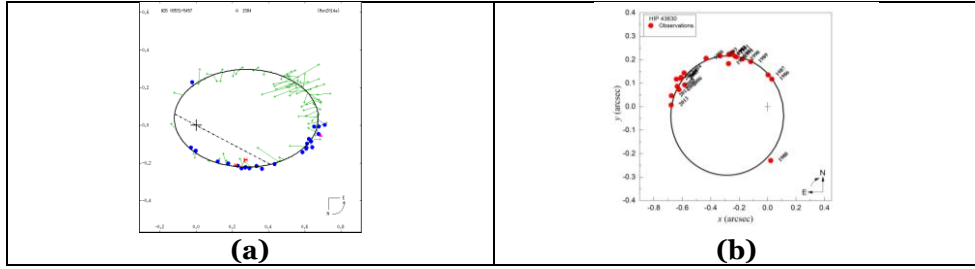


Figure 2: (A) The Visual Orbit of the Hip 43630 System as Observed By Tokovinin, et al. [16]. (B) The Relative Visual Orbit of the System with the Epoch of the Positional Measurement.

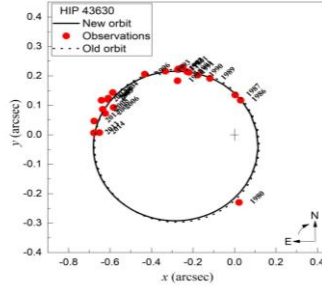


Figure 3: The Modified Orbit of the HIP 43630(HD 75553) System as Determined from Our (Solid Line) and Last Orbit From [16] (Dotted Line).

Table 4: Dynamical Mass of HIP 43630(HD 75553) .(*): Based on parallax Hipparcos and Tycho Catalogues [7] ($\pi = 18.23 \pm 1.08 \text{ mas}$) (**): Based on Hipparcos reduced catalog [17] ($\pi = 19.19 \pm 0.73 \text{ mas}$) ***: Based on Gaia Early Data Release 3 [9] ($\pi = 19.67848 \pm 0.173 \text{ mas}$).

Dynamical mass		
	By (A. Tokovinin et al., 2015)	This work
$\pi_{\text{Hip 1997}}^*$	2.4161	2.4466 ± 0.4442
$\pi_{\text{Hip 2007}}^{**}$	2.0713	2.0974 ± 0.25162
$\pi_{\text{Hip GEDR3}}^{***}$	1.9209	1.9451 ± 0.08836

Conclusions

We have refined the orbits of the close visual binary system HIP 43630(HD 75553). The realistic and accurate determination of the most recent trigonometric parallax values from Gaia has provided the means to present a solution for this system. The Tokovinin's method enables the determination of precise orbital elements for close visual binary systems. This investigation refines the orbital elements and computes the total masses of HIP 43630(HD 75553), capitalizing on the Hipparcos trigonometric parallax and Gaia Early Data Release 3 measurements. The orbital solutions presented in this work demonstrate improved accuracy compared to previous estimates and align more closely with the updated observational data. Forthcoming Gaia data releases and angular separation (ρ) and position angle (θ) measurements from the Fourth Catalog of Interferometric Measurements (INT4) of Binary Stars will prove crucial for refining the orbital solutions and enhancing our understanding of the HIP 43630 (HD 75553) binary system. Furthermore, this study underscores the importance of sustained observations of speckle interferometric binary systems over an extended timeframe, even as orbital models have been established for several close visual binary systems.

Acknowledgments

This study has made use of the SIMBAD database, it has also utilized data from the SAO/NASA, Fourth Catalog of Interferometric Measurements of Binary Stars, the IPAC data systems, the Sixth Catalog of Orbits of Visual Binary Stars, and the ORBITX code.

References

- [1] M. Abu-Saleem, A. Taani, *Geometric Transformations on a Topological Black Hole and Their Applications*, Chin. J. Phys., Taipei **74** (2021), 53-59.
- [2] Y. M. Al-Tawalbeh, A. M. Hussein, A. A. Taani, A. A. Abushattal, N. A. Yusuf, M. K. Mardini, F. A. Suleiman, H. M. Al-Naimiy, A. M. Khasawneh, M. A. Al-Wardat, *Precise Masses, Ages, and Orbital Parameters of the Binary Systems HIP 11352, HIP 70973, and HIP 72479*, Astrophysical Bulletin **76** (2021), 71-83.
- [3] H. Aljboor, A. Taani, *Speckle-interferometric Study of Close Visual Binary System HIP 11253 (HD 14874) using Gaia (DR2 and EDR3)*, Research in Astronomy and Astrophysics **23** (2023), 075018.
- [4] A. G. A. Brown, A. Vallenari, T. Prusti, J. H. De Bruijne, C. Babusiaux, M. Biermann, O. L. Creevey, D. W. Evans, L. Eyer, A. Hutton, *Gaia early data release 3-summary of the contents and survey properties*, Astron. Astrophys. **649** (2021), 1-20.
- [5] CDS, *SIMBAD Astronomical Database - CDS (Strasbourg)*, SIMBAD. <https://simbad.cds.unistra.fr/simbad>, n.d.
- [6] A. Duquennoy, M. Mayor, *Multiplicity among Solar Type Stars in the Solar Neighbourhood-Part Two-Distribution of the Orbital Elements in an Unbiased Sample*, Astron. Astrophys. **248** (1991), 485-524.
- [7] ESA, *The Hipparcos and Tycho Catalogues*, ESA SP-1200, European Space Agency. <https://www.cosmos.esa.int/web/hipparcos/catalogues>, 1997.
- [8] D. A. Fischer, G. W. Marcy, *Multiplicity among M dwarfs*, The Astrophysical Journal **396** (1992), 178-194.

- [9] Gaia Collaboration, *VizieR online data catalog: Gaia edr3* (gaia collaboration, 2020), VizieR Online Data Catalog, 2020.
- [10] E. Hog, C. Fabricius, V. V. Makarov, S. Urban, T. Corbin, G. L. Wycoff, U. Bastian, P. Schwekendiek, A. Wicenec, *The Tycho-2 Catalogue of the 2.5 million brightest stars*, Astron. Astrophys. **363** (2000), 385-390.
- [11] J. L. Prieur, M. Scardia, L. Pansecchi, R. W. Argyle, A. Zanutta, E. Aristidi, *Speckle observations with PISCO in Merate (Italy): XV: Astrometric measurements of visual binaries in 2014, and new orbits for ADS 671, 1615, 1709, 5447, 10075, and 12447*, Astron. Nachr. **338** (2017), 74-90.
- [12] R. L. Riddle, A. Tokovinin, B. D. Mason, W. I. Hartkopf, L. C. Roberts Jr, C. Baranec, N. M. Law, K. Bui, M. P. Burse, H. Das, *A survey of the high order multiplicity of nearby Solar-type binary stars with Robo-AO*, The Astrophysical Journal **799** (2015), 4.
- [13] E. F. Schlafly, D. P. Finkbeiner, *Measuring reddening with Sloan Digital Sky Survey stellar spectra and recalibrating SFD*, The Astrophysical Journal **737** (2011), 103.
- [14] A. Taani, J. C. Vallejo, M. Abu-Saleem, *Assessing the complexity of orbital parameters after asymmetric kick in binary pulsars*, Journal of High Energy Astrophysics **35** (2022), 83-90.
- [15] A. Tokovinin, *Orbits of four young triple-lined multiple systems*, The Astronomical Journal **152** (2016), 11.
- [16] A. Tokovinin, B. D. Mason, W. I. Hartkopf, R. A. Mendez, E. P. Horch, *Speckle Interferometry at SOAR in 2014*, The Astronomical Journal **150** (2015), 50.
- [17] F. Van Leeuwen, *Validation of the New Hipparcos Reduction*, Astron. Astrophys. **474** (2007), 653-664.
- [18] H. Widyan, H. Aljboor, *Physical and orbital properties of the stellar system HIP 43766*, Research in Astronomy and Astrophysics **21** (2021), 110.