TRIPLE STAR PARAMETERS AND MASSES

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ABSTRACT

A non-negligible number of orbital visual binaries, suitable for mass-determination using the Hipparcos parallaxes, are members of visual multiple systems. The extra component(s) were not always taken into account in the standard Hipparcos reductions, but starting from the intermediate 'Transit Data', supplemented by speckle interferometry and/or reliable earlier orbits, it it possible to make more complete use of the Hipparcos data. A few examples of such combined triple star solutions are given, including new mass-determinations for the close pair.

Key words: space astrometry; multiple stars; orbits; masses.

1. INTRODUCTION

The Hipparcos Catalogue (ESA 1997) was published in June 1997. It is based on the reduction work performed in the consortia NDAC and FAST as completed in early 1996. Because of severe time-constraints, the observational data for multiple stars were not fully exploited, and in many cases a known triple star was only solved as a double.

As noted in a study of mass-determinations in orbital binaries (Söderhjelm et al. 1997), several known binary orbits are indeed accompanied by a wide component. Any such component closer than about 25 arcsec from the orbit pair was by design (size of the effective field of view) included in the Hipparcos observations, and needs to be taken into account. Even if one is only interested in the data for the close binary, these can only be obtained through a full multiple star reduction. In order to make such improved reductions, the general idea is to fit the intermediate 'Hipparcos Transit Data' to a realistic model for the multiple object, using also the available ground-based observations. In this way, the binary orbits in multiple star systems can potentially be used for new mass-determinations. So far, only four 'orbit + single' triples have been studied, but this shows conclusively the feasibility of such combined solutions. In further applications, it should be easy to extend these methods to more components/orbits, as might be needed in individual cases.

2. PRINCIPLES FOR THE ORBIT DETERMINATIONS

The basic principles are described in the paper about mass-determination for orbital binaries (Söderhjelm et al. 1997). As in these solutions, the observational input consists of two different types of data. First, we have the $b_1 - b_5$ 'Hipparcos Transit Data', together with full information about the scanning geometry, at each of some 100 epochs (1990–1993). This gives absolute position information about the (now) three components in the system, and also about e.g. the system parallax. Secondly, we have standard relative double-star observations for the close binary in the system. Speckle-interferometry observations were taken when available from the WWW-version of the Third CHARA Catalogue by Hartkopf et al. (1996a). Lower-weight visual observations were often also needed, mostly taken from the references given in Worley & Heintz (1983).

The basic model to be fitted is an orbital binary plus a third component which can always be assumed to move rectilinearly over the 3-year Hipparcos interval. The positions of each of the two close components are specified by the mass-ratio (q), the seven orbital elements ($P, T, a, e, i, \omega, \Omega$), plus the five astrometric parameters ($\alpha, \delta, \mu_\alpha, \mu_\delta, \pi$) for the centre of mass. The third component has two position and two proper motion offsets relative to the centre of mass of the binary, but can normally be assumed to have the same parallax. To this has to be added the three magnitudes (Hp_i) in the Hipparcos magnitude system, altogether 20 parameters. (The mass-ratio in the close pair can in principle be determined if the orbit shows enough curvature, but for the systems so far treated, it was arbitrarily set to unity). This model was again implemented in the GaussFit environment (Jefferys et al. 1988), and apart from a slower execution and more sensitivity to correct start values, the processing was rather straightforward.

3. TEST SOLUTIONS

The first two systems tested have a basically correct triple star solution in the Hipparcos Catalogue, but the close orbits may now be studied in more detail using additional ground-based data. The other two are more difficult cases with only a double star solution in the Hipparcos Catalogue.

Table 1. *Optimum parameters for Kui 83 (HIP 86221) from the present combined solutions, and comparison with previous (partial) determinations. (The mass-ratio m_B/m_A is arbitrarily set to unity, and thus the position of the 'centre of mass' AB from the Hipparcos Catalogue is simply the unweighted mean of the positions given for A and B).*

parameter	[unit]	solution	(m.e.)	HIP	(m.e.)	sol.-HIP	Baize (1972)
α_{AB}	[deg (mas)]	264.29510801	(1.7)	264.29510817	(7.7)	−0.3	–
δ_{AB}	[deg (mas)]	27.89584248	(4.7)	27.89584290	(12.3)	+4.7	–
α_C	[deg (mas)]	264.29777644	(8.6)	264.29777625	(20.1)	+0.7	–
δ_C	[deg (mas)]	27.89699846	(12.9)	27.89699983	(32.1)	−4.9	–
$\mu_\alpha(AB)$	[mas/yr]	−88.6	(1.7)	−87.4	(5.6)	−1.2	–
$\mu_\delta(AB)$	[mas/yr]	244.4	(2.6)	246.0	(6.1)	−1.6	–
$\mu_\alpha(C)$	[mas/yr]	−111.5	(13.0)	−99.1	(16.5)	−12.4	–
$\mu_\delta(C)$	[mas/yr]	221.3	(19.8)	227.2	(22.6)	−5.9	–
π	[mas]	31.56	(1.78)	32.05	(2.28)	−0.49	–
P_{BC}	[yrs]	24.02	(0.05)	–	–	–	24
T	[AD]	1961.3	(0.13)	–	–	–	1961.7
a	[arcsec]	0.289	(0.003)	–	–	–	0.273
e		0.210	(0.005)	–	–	–	0.21
i	[deg]	165.8	(3.7)	–	–	–	159
ω	[deg]	190	(13)	–	–	–	233
Ω	[deg]	140	(13)	–	–	–	176
Hp(A)	[mag]	9.796	(0.023)	9.813	(0.081)	−0.017	–
Hp(B)	[mag]	10.406	(0.041)	10.404	(0.140)	+0.002	–
Hp(C)	[mag]	11.911	(0.033)	11.888	(0.115)	+0.023	–

Table 2. *Optimum parameters for h 3556 (HIP 14913) from the present combined solutions, and comparison with previous (partial) determinations. (The mass-ratio m_B/m_A is arbitrarily set to unity).*

parameter	[unit]	solution	(m.e.)	HIP	(m.e.)	sol.-HIP	Heintz (1979)
α_{AB}	[deg (mas)]	48.10699379	(0.6)	48.10699382	(1.4)	−0.1	–
δ_{AB}	[deg (mas)]	-44.41974845	(0.6)	27.89584290	(1.3)	+0.1	–
α_C	[deg (mas)]	48.10664305	(3.3)	48.10664346	(9.6)	−1.1	–
δ_C	[deg (mas)]	−44.42067777	(3.7)	−44.42067744	(10.7)	−1.2	–
$\mu_\alpha(AB)$	[mas/yr]	89.8	(0.7)	90.1	(1.1)	−0.3	–
$\mu_\delta(AB)$	[mas/yr]	−12.1	(0.7)	−11.7	(1.0)	−0.4	–
$\mu_\alpha(C)$	[mas/yr]	90.8	(4.6)	87.1	(7.5)	+3.7	–
$\mu_\delta(C)$	[mas/yr]	−19.8	(4.7)	−18.2	(7.6)	−1.6	–
π	[mas]	22.98	(0.71)	22.83	(0.78)	+0.15	–
P_{BC}	[yrs]	45.15	(0.17)	–	–	–	44.82
T	[AD]	1977.51	(0.15)	–	–	–	1977.08
a	[arcsec]	0.413	(0.010)	–	–	–	0.443
e		0.895	(0.010)	–	–	–	0.897
i	[deg]	165.0	(assumed)	–	–	–	157
ω	[deg]	118.3	(64)	–	–	–	111
Ω	[deg]	110.5	(66)	–	–	–	105
Hp(A)	[mag]	6.554	(0.001)	6.557	(0.005)	−0.003	–
Hp(B)	[mag]	7.261	(0.002)	7.268	(0.006)	−0.007	–
Hp(C)	[mag]	9.107	(0.016)	9.092	(0.054)	+0.015	–

3.1. Kui 83

Kui 83 (= HIP 86221 = CCDM 17372+2754) is a red-dwarf triple consisting of a close visual AB pair (24-yr period) with a physical C-component at 10 arcsec. The new solution used numerous speckle observations from the Third CHARA Catalogue, the visual observations listed by Baize (1972) and the Hipparcos Transit Data. The convergence was exemplarly, and as shown in Table 1, there is good agreement with the earlier data. The low inclination makes the nodal line uncertain, but the difference $\Omega - \omega$, corresponding to the position angle of periastron, is well-defined. From the values in Table 1, we may estimate a mass-sum 1.33(0.24) $M_\odot$ for the AB pair. Using the magnitude difference as a clue to the mass-ratio, we get the very reasonable individual masses 0.70 and 0.63 $M_\odot$. The main uncertainty comes from the relatively large parallax mean error, due essentially to the faintness (for Hipparcos) of the system. Improved parallax determinations from the ground might be feasible by concentrating on the undisturbed C component.

3.2. h 3556

h 3556 (= HIP 14913 = CCDM 03124-4425) is a typical southern system with only a single good speckle observation. The observed separations (AB 0.7 arcsec, AB-C 3.5 arcsec) are unusually similar for a hierarchical triple, but this is most probably due to projection effects and not to an unusual period-ratio. Using the visual data listed by Heintz (1979), covering more than 1.5 revolutions, it was still possible to get the realiable combined solution in Table 2. Again, the parameters given in the Hipparcos Catalogue are reproduced closely, but with appreciably reduced mean errors. By chance, this orbit too has a low, retrograde inclination arbitrarily fixed at 165 degrees. As before therefore, only $\Omega - \omega$ is significant, and not their individual values. The data in Table 2 give a mass-sum about 2.84(0.50) $M_\odot$ for AB, about correct for an F-type main-sequence pair. (As noted already by Heintz, an F6 III classification for the primary spectrum is clearly an error).

3.3. ϵ Hydrae

ϵ Hya (= HIP 43109 = CCDM 08468+0625) is a quintuple system consisting of a close visual AB pair (15-yr period) in a 900-yr orbit with the C component (which is a 9 day SB1), plus a faint D component at 19 arcsec. In the Hipparcos Catalogue, only an (AB)-C double solution is given, although AB should have been easily resolved. Using the 40 speckle observations of AB listed in the Third CHARA Catalogue, the combined triple star solution in Table 3 was obtained. As expected, the relative orbit agrees very well with that derived by Hartkopf et al. (1996b), but for the proper motions, there are some differences with respect to the Hipparcos Catalogue. The present values seem preferrable, however, giving a clearly better fit to the observed long-period (AB)-C motion. The mass-sum obtained for AB, 5.2(0.7) $M_\odot$, is probably a bit high for this G0III+A8IV pair with absolute Hp magnitudes 0.9+1.7, and a further (spectroscopic) component can not be excluded.

3.4. γ Andromedae

γ And (= HIP 9640 = CCDM 02039+4220) has only a 10 arcsec double solution in the Hipparcos Catalogue, although the BC separation in this well-known visual triple is above 0.5 arcsec. (Actually, the B-component is also a double-lined spectroscopic binary, but this 2.7 day pair is unresolved by Hipparcos). The full triple solution uses as inputs the old visual observations (Muller 1957), the speckle data (Third CHARA Catalogue) plus the Transit Data from the Hipparcos Catalogue, but there are obvious problems. Most seriously, component A is about 4 magnitudes brighter than C, and it is also slightly variable. Then the BC orbit has high eccentricity and inclination, and the speckle-data cover only the apastron part (cf. Figure 1). For these reasons, the full 19-parameter equations do not easily converge, but with some manual search over the parameter-space, the reasonable solution in Table 4 was obtained. The Hipparcos Catalogue solution refers mainly to the AB pair (the BC separation being too large to give

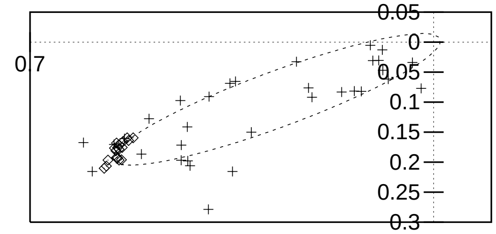

Figure 1. Visual (crosses) and speckle (diamonds) observations of γ And BC, with the derived orbit.

a good photocentre), and the parallax values differ a bit more than usual. The full solution gives well-defined values for the BC a and P, and the new and Hipparcos parallaxes give then mass-sums [6.5(1.5)/9.4(2.2) $M_\odot$] that probably bracket the true mass of the BC (B9.5+B9.5+A0) triple subsystem.

4. CONCLUSION

For many multiple systems, as known and documented in the catalogue documentation, the Hipparcos Catalogue data are incomplete. The present work shows that more comprehensive solutions (using also the available ground-based data) can be obtained from the intermediate Transit Data. In principle, 'new' reductions, using arbitrarily complex models, may at any time be performed, fitting the model to the (old) Hipparcos observations. The proviso is only that the object was known or suspected of being non-single, as the Transit Data were only derived for that subset of the Hipparcos entries.

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Table 3. Optimum parameters for ϵ Hydrae (HIP 43109) from the present combined solution, and comparison with previous (partial) determinations. (The mass-ratio m_B/m_A is arbitrarily set to unity).

parameter	[unit]	solution	(m.e.)	HIP	(m.e.)	sol.-HIP	Hartkopf et al. (1996b)
α_{AB}	[deg (mas)]	131.69435923	(1.0)	131.69435930	(1.2)	–0.3	–
δ_{AB}	[deg (mas)]	6.41890821	(0.7)	6.41890691	(0.8)	+4.7	–
α_C	[deg (mas)]	131.69361277	(7.5)	131.69361367	(26.5)	–3.2	–
δ_C	[deg (mas)]	6.41919637	(4.5)	6.41919781	(18.1)	–5.2	–
$\mu_\alpha(AB)$	[mas/yr]	–198.0	(2.0)	–231.0	(1.5)	+33.0	–
$\mu_\delta(AB)$	[mas/yr]	–50.4	(1.1)	–40.2	(1.0)	–10.2	–
$\mu_\alpha(C)$	[mas/yr]	–209.1	(10.7)	–262.0	(22.8)	+52.9	–
$\mu_\delta(C)$	[mas/yr]	–21.7	(6.9)	14.0	(14.7)	–36.4	–
π	[mas]	24.26	(1.01)	24.13	(1.29)	+0.13	–
P_{BC}	[yrs]	15.07	(0.03)	–	–	–	15.05
T	[AD]	1976.19	(0.03)	–	–	–	1991.25
a	[arcsec]	0.257	(0.003)	–	–	–	0.255
e		0.653	(0.005)	–	–	–	0.656
i	[deg]	50.5	(0.9)	–	–	–	50.0
ω	[deg]	265.8	(1.0)	–	–	–	266.1
Ω	[deg]	108.6	(1.2)	–	–	–	108.0
Hp(A)	[mag]	3.959	(0.013)	–	–	–	–
Hp(B)	[mag]	4.798	(0.029)	–	–	–	–
Hp(A+B)	[mag]	3.547	(0.001)	3.561	(0.005)	–0.014	–
Hp(C)	[mag]	6.885	(0.019)	6.665	(0.093)	+0.220	–

Table 4. Optimum parameters for γ Andromedae (HIP 9640) from the present combined solution, and comparison with previous (partial) determinations. (The mass-ratio m_C/m_B is arbitrarily set to unity).

parameter	[unit]	solution	(m.e.)	HIP	(m.e.)	sol.-HIP	Muller (1957)
α_A	[deg(mas)]	30.97466246	(0.6)	30.97466283	(0.7)	–0.1	–
δ_A	[deg(mas)]	42.32984869	(0.5)	42.32984832	(0.6)	+0.1	–
α_{BC}	[deg(mas)]	30.97794853	(4.0)	30.97785767	(10.2)	+243.1	–
δ_{BC}	[deg(mas)]	42.33104810	(2.5)	42.33107165	(8.4)	–86.7	–
$\mu_\alpha(A)$	[mas/yr]	42.8	(0.6)	43.1	(0.7)	–0.3	–
$\mu_\delta(A)$	[mas/yr]	–50.5	(0.6)	–50.8	(0.6)	+0.3	–
$\mu_\alpha(BC)$	[mas/yr]	46.4	(3.8)	43.1	(0.7)	+3.3	–
$\mu_\delta(BC)$	[mas/yr]	–45.4	(3.2)	–50.8	(0.6)	+5.4	–
π	[mas]	10.42	(0.73)	9.19	(0.73)	+1.23	–
P_{BC}	[yrs]	61.3	(0.5)	–	–	–	61.1
T	[AD]	1952.3	(0.5)	–	–	–	1952.1
a	[arcsec]	0.302	(0.003)	–	–	–	0.296
e		0.952	(0.005)	–	–	–	0.93
i	[deg]	119.9	(4.5)	–	–	–	111
ω	[deg]	183.8	(6.5)	–	–	–	171
Ω	[deg]	111.2	(3.3)	–	–	–	104
Hp(A)	[mag]	(var)	–	2.328	(0.005)	–	–
Hp(B)	[mag]	5.197	(0.011)	5.021	(0.050)	+0.176	–
Hp(C)	[mag]	6.338	(0.032)				–