The Rapid Convergence of 44 Boötis with Revised Orbit and Updated Ephemerides

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Abstract: In this article I investigate the apparent orbital motion for the visual double star 44 Boötis (WDS 15038+4739, *i* Boötis) near periastron. Observations from about 200 years and the comparison with recent orbit references from the literature show systematic increasing differences between observed and calculated positions in polar coordinates. The current separation of the components of 1.6 arcsec is expected to approach 0.2 arc seconds in the next 10 years. Based on the calculation of a new and improved orbit and updated ephemeris, the expected positions are predicted more accurately.

Introduction

The visual double star 44 Boötis, also known as *i* Boötis, ADS 9494, WDS 15038+4739, STF1909 AB, HD133640, HIP73695, HR5618, is a 4.8 magnitude (visual) bright star located in constellation Boötes. The coordinates in IRCS epoch 2000 are right ascension 15h 03m 47sec and declination +47° 39' 14". Sir William Hershel discovered this pair in 1781 and a few decades later, Friedrich Georg Wilhelm Struve confirmed the visual duplicity. The supposed variability in brightness was investigated by Schilt (1926) and he established variability with a period of about 6.4 hours. Recently detailed results of an investigation into this eclipsing binary component, located in component 44 Boötis B, were given by Liu, *et al.* (2001) and Pribulla (2001). The corresponding weakening in brightness due to the variability of 44 Boötis B is less than 0.2 magnitudes from the combined light. The difference in brightness between the visual components is about 0.8 magnitude.

Motivation

44 Boötis is one of the relatively bright interesting systems for visual double star observers; the apparent motion of both components is nearing a phase of rapid change. Presently, the distance is near 1.6 arc seconds and is just possible to resolve with a small aperture telescope. But in the coming 10 years, the components will approach to about 0.2 arc seconds, which will lead to increasing requirements on telescope resolution power. Therefore, this pair offers the opportunity to check the resolution of one's equipment.

With the separation nearing distances of 0.2 arc seconds, techniques such as speckle interferometry will be increasingly more important. A good overview of the application of speckle interferometry with amateur means was given by Joerg Schlimmer (Schlimmer, 2008).

For checking the quality of these measurements, it's necessary to use ephemerides from a recent orbit calculation. This information can be easily obtained from the *Sixth Catalog of Orbits of Visual Binary Stars* (Hartkopf & Mason, 2010). If one can accept the ephemeris as trustworthy, it is a good way to check the one's own measurements.

In case of 44 Boötis, I don't trust the orbit quality from the two latest published orbits, especially due

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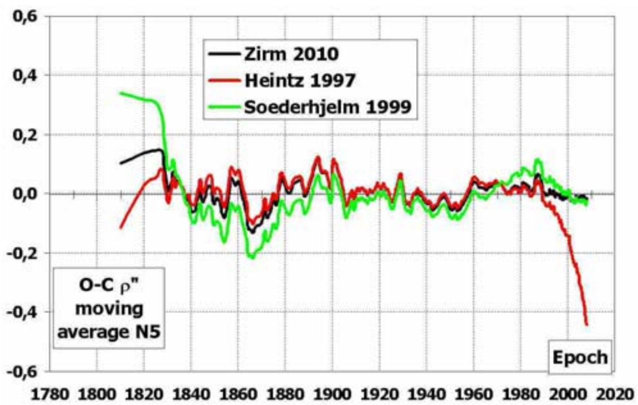

Figure 1: 44 Boötis, residuals in Rho vs. time

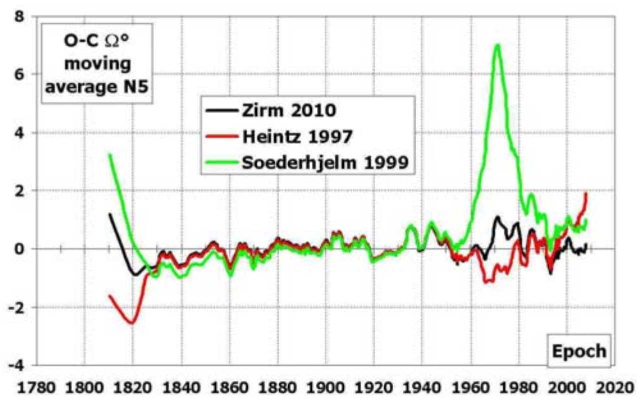

Figure 2: 44 Boötis, residuals in Theta vs. time

to the rapid motion for next decade and the definitely decreasing separations since 2000. Before year 2000, the end of growing distances was not clear enough.

I have calculated residuals from the large observational data (see the section titled Preparation), based on the two most recent orbits (Soederhjelm, 1999 and Heintz, 1997). For evaluating the quality of these orbits and consequently the plausibility of needed ephemerides for the next decade, I've checked the residuals via graphical representation in Theta vs. time and in Rho vs. time.

In case of Heintz orbit, particularly since 1990, the residuals in distance are especially enlarged and for recent measures the residuals |O-C r"| have increased up to about -0.4 arc seconds (Figure 1, moving average).

The residuals from Soederhjelm's orbit shows a large error, surprisingly especially in the time interval about 1960 to about 1990. Since 1960 a clear systematic growing error in position angle |O-C W°| is visible (Figure 2, moving average), after the maximum error with 7° (Theta) in 1972, the residuals decreasing to "normal" in year 1990. One important fact should be noted, the author had in all probability used measurements up to Epoch 1999. So I suppose any mistakes in orbit computation, particularly in estimation of weightings (see Preparation). This fact leads to a probable overestimated eccentricity in the Soederhjelm orbit and accordingly the time of closest approach is 1 year earlier than estimated by me.

As a result to get more probability estimation for positions on the apparent orbit for the next 10 years, I have decided to calculate a new orbit. Below I described shortly the steps to get a new orbit for 44 Boötis.

Preparation

Most observations I used were from the Washington Double Star Catalog, obtained via email request from Brian D. Mason and his colleagues. Other measurements were recently reported in the *Journal of Double Star Observations* (Anton 2010 and Schlimmer 2010).

Initially, all position angles were corrected for precession to epoch 2000 (Heintz, 1978).

In case of 44 Boötis the influence of proper motion was ignored.

Furthermore, I divided all observations in three classes: visual observations, photographic and CCD observations and speckle measures (including Hipparcos). For each class it's useful to create normal points, in case of 44 Boötis, all observations from the same year have to be merged into a weighted average. An example is shown in Figure 3.

The extracted information for a single visual normal point at Epoch 1879 is:

t	1879.488
Theta	240.5
Rho	4.90
Observers	Sp_6 Hod4 Sbk3 Prc2 Sbk3 Je_3

Date	P.A.	Sep.	Mag-a	Mag-b	#	RefCode	Aperture	Method
.								
.								
.								
1879.18	240.4	4.76	.	.	6	Sp_1888	09	A
1879.44	240.1	4.80	.	.	4	Hod1881	8	A
1879.55	241.9	5.04	.	.	3	Sbk1881	8	A
1879.59	238.2	4.88	.	.	2	Prc1887	12	A
1879.63	241.4	5.01	.	.	3	Sbk1881	8	A
1879.66	241.5	4.97	.	.	3	Je_1882	06	A
.								
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Figure 3: 44 Boötis, example observation data file extraction from WDS

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I'll not describe here the topic of calculating weights. But, I recommend publications from well known double star observers such as Wulff D. Heintz, (Heintz 1967, Heintz 1978), J.D. Docobo (Docobo & Ling, 2003), and from the CHARA team (Mason, *et al.*, 1999).

All computed normal point observations and combined with calculated residuals, are shown in Table 4, Appendix A.

Orbit calculation

Numerous methods for orbit computation exist in the literature as well as many methods to improve a given (more or less preliminary) orbit. In *Observing and Measuring Visual Double Stars* (Argyle, ed., 2004) chapters 7 and 8 by A. Alzner, are detailed and clearly arranged information about the fundamentals of orbit and ephemerides computation and references to further readings.

In case of 44 Boötis, I used the method of least squares. I have two important reasons for this decision: first, the observation data set is large and consistent and second, on basis of the two recent orbits (Heintz, 1997 and Soederhjelm, 1999) the residuals showed systematic trends and affected only single parts of the apparent orbital path.

So I tried an improvement on the basis of existing orbits using the well-described method of least squares in polar coordinates by Heintz (1967, 1978). On basis of weighted normal equations (see literature references in the section Preparation), I obtained differential corrections and transformed into the dynamical orbital elements for period **P** in years, the time of periastron passage **T**, the numerical eccentricity **e**, the semi major axis **a** in arc seconds and finally the elements from apparent orbit: the position angle of node **Ω** in degrees, the inclination **i** in degrees and the argument of periastron **ω**. The uncertainties were derived from the covariance matrix of normal equations and the sum of residuals in both polar coordinates.

Figure 4 shows the retrograde apparent orbital motion on basis of the new elements and the normal points of used observations. The scale is 1 arc second per large tic.

The resulting (so called Campbell-) elements are listed in Table 1, combined with the previously discussed recent orbit results.

Ephemerides: I'll give a brief overview how to compute ephemerides respectively residuals on basis of present measurements (t_i, ϑ_i, ρ_i) and the desired orbital elements (P, T, e, a, i, ω, Ω_{2000}).

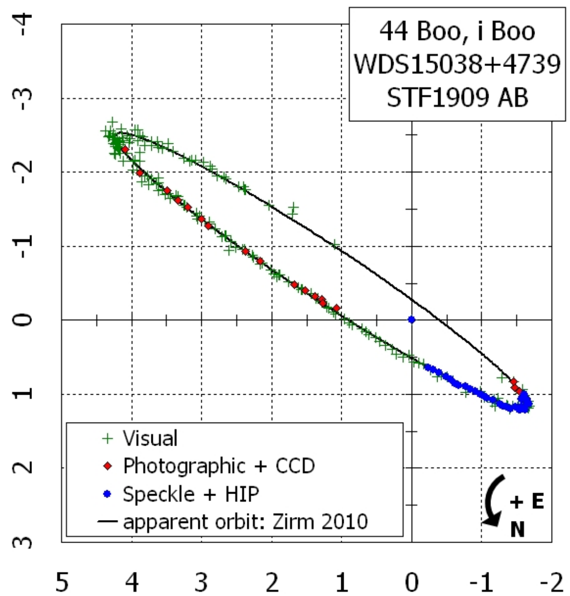

Figure 4: 44 Boötis, apparent orbit from new orbital elements, normal points visible for visual, photographic/CCD and speckle measures.

The Kepler equation is the correlation between mean anomaly M and eccentric anomaly E and is calculated by:

$$M = E - \sin E$$

M is defined as:

$$M = \mu(t_i - T) = 360° \, (t_i - T) \, / \, P$$

Heintz (1978) gave an easy, iterative, method to determine the eccentric anomaly E:

$$E_o = M + e \sin M + (e^2 / M) \sin(2M)$$

With E_0 calculate M_0:

Table 1: 44 Boötis, new orbital elements and uncertainties

	Zirm 2010		Hei1997	Sod1999	unit
P	209.8	±3.3	220.0	206	years
T	2012.04	±0.26	2017.0	2013	
e	0.5111	±0.0065	0.451	0.55	
a	3.666	±0.021	3.70	3.8	arcsec
i	83.55	±0.05	83.7	84	degree
ω	39.86	±0.68	37.5	45	degree
Ω_{2000}	57.14	±0.06	57.7	57	degree

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$$M_o = E_o - e\sin E_o$$

The next step is calculating E_1 from E_0 and M_0:

$$E_1 = E_o + (M - M_o)/(1 - e\cos E_o)$$

Using the last two formulas for four more iterations, the accuracy should be sufficient for ephemerides calculation in case e ≤ 0.95.

For a given epoch, the theoretical positions in polar coordinates can then be calculated. The value ν is the true anomaly and r is the radius vector:

$$\tan(\nu/2) = \sqrt{(1+e)/(1-e)}\,\tan(E/2)$$
$$r = a(1-e^2)/(1+e\cos\nu)$$
$$\tan(\theta - \Omega) = \tan(\nu + \omega)\cos i$$
$$\rho = r\cos(\nu+\omega)\sec(\theta+\Omega)$$

With this simple "tool" it is quick and easy to compute theoretical positions for each time. Calculate residuals for Epoch *i* via:

$$\text{O-C } \vartheta_{2000\,i} = \vartheta_{\text{observed (corrected for precession) } i} - \vartheta_{\text{calculated I}}$$
$$\text{O-C } \rho_i = \rho_{\text{observed } i} - \rho_{\text{calculated } i}$$

The estimated ephemerides for the new and the two recent 44 Boötis orbits are listed for comparison in Table 2. The probable year of closest approach is characterized by bold letters.

A detailed view of the apparent orbit is given in Figure 5, additionally included are points of coming yearly ephemerides for the new orbit and those from Soederhjelm orbit:

For clarity, alternatively in Figure 6 the theoretical evolution of separations (ρ in arc seconds) in the next two decades is shown.

The Heintz orbit (1997) is definitely not in line with actual measurements. A clear indication that the new calculated orbit is a better interpretation than Soederhjelm's, seems to be the discussed systematic errors during the last approach phase 1960 – 1990.

Table 2: 44 Boötis, Ephemerides from 2011 to 2030

	Zirm 2010		Heintz 1997		Soederhjelm 1999	
t	$J°_{2000}$	r"	$J°_{2000}$	r"	$J°_{2000}$	r"
2011.0	61.4	1.502	58.7	2.083	60.6	1.490
2012.0	62.5	1.386	59.2	2.028	61.6	1.359
2013.0	63.7	1.260	59.8	1.963	63.0	1.216
2014.0	65.3	1.125	60.4	1.890	64.7	1.061
2015.0	67.3	0.983	61.0	1.807	67.0	0.896
2016.0	70.0	0.835	61.7	1.716	70.4	0.725
2017.0	73.9	0.684	62.5	1.617	75.9	0.551
2018.0	80.0	0.533	63.4	1.511	86.4	0.382
2019.0	90.8	0.390	64.4	1.397	111.1	0.241
2020.0	112.2	0.273	65.7	1.277	**161.4**	**0.207**
2021.0	**150.4**	**0.230**	67.2	1.152	196.9	0.319
2022.0	185.1	0.297	69.0	1.022	211.4	0.482
2023.0	203.0	0.424	71.4	0.889	218.3	0.658
2024.0	212.2	0.571	74.7	0.754	222.3	0.835
2025.0	217.6	0.725	79.4	0.620	224.9	1.011
2026.0	221.1	0.880	86.7	0.489	226.8	1.184
2027.0	223.5	1.034	98.9	0.370	228.2	1.352
2028.0	225.3	1.186	120.5	0.281	229.2	1.517
2029.0	226.7	1.335	**152.7**	**0.255**	230.1	1.677
2030.0	227.9	1.482	181.5	0.311	230.8	1.832

Discussion

I will now compare the new orbit with the older orbits. One of the main reasons why astronomers calcuate visual (and spectroscopic) binary orbits is that in combination with a good estimate of the distance, it is one of the most direct routes to obtain stellar masses. However, to get the information about the masses of each component we need the mass ratio (M_B/M_A). Many techniques are available, for instance: mass ratio from double lined spectroscopic orbits or astrometric or photocentric motion of main component from long time photographic investigations. In case of 44 Boötis, I used another way. As described in the Introduction, it's known that component B is an eclipsing binary. From recent photometric and spectroscopic investigations made by Liu et al. (2001) and Pribulla (2001), the values for inclination and minimum mass for 44 Boötis B are available. Hence the derived mass (in unit of solar masses) for component B is:

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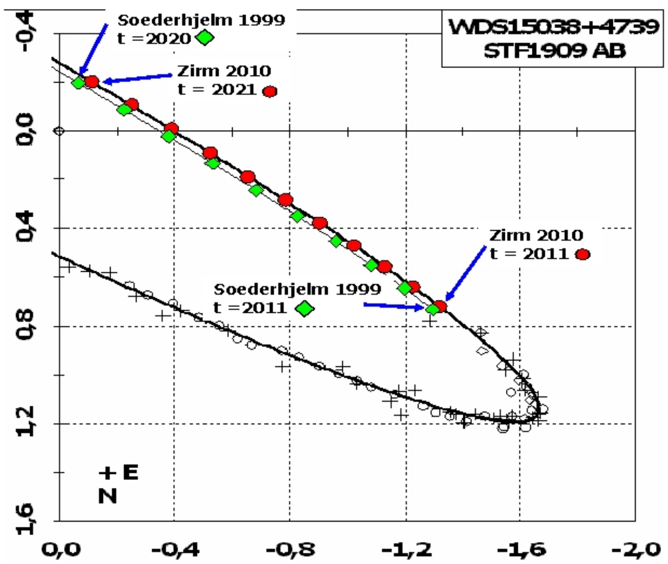

Figure 5: 44 Boötis, detail of apparent orbit and yearly ephemerides points from new orbit and those from Soederhjelm orbit.

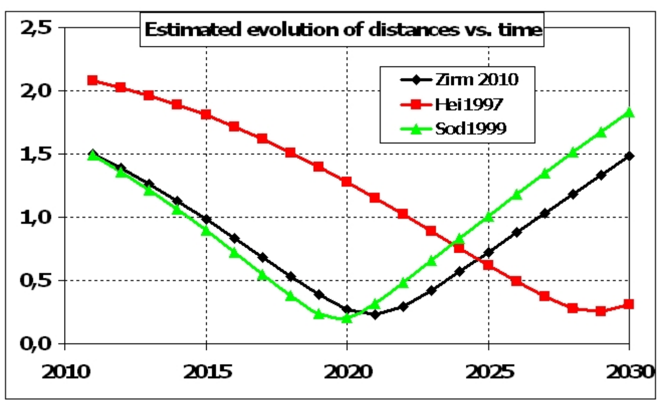

Figure 6: 44 Boötis, estimated evolution of distances (in arc seconds) vs. time

$$M / M_{\odot B} = 1.28 \pm 0.02$$

With a known parallax (π in arc seconds), the period (P in years) and the semi major axis (a in arc seconds), the sum of the masses can be calculated from Kepler's third law:

$$\Sigma M = M_A + M_B = a^3 / (\pi^3 P^2)$$

Furthermore, the mass uncertainty is

$$\sigma \Sigma M = \Sigma M \sqrt{9(\sigma a / a)^3 + 9(\sigma \pi / \pi)^3 + 4(\sigma P / P)^2}$$

Now the mass (and a simplified estimation for the mass error) are calculated for the A component.

$$M_A = \Sigma M - M_B; \quad \sigma M_A = \sigma \Sigma M - \sigma M_B$$

The recent parallax value comes from "Hipparcos, the New Reduction of the Raw Data" (van Leeuwen, 2007) and was:

$$\pi = 0.07838 \pm 0.00103 \text{ (arc seconds)}$$

or,

$$\text{distance} = 12.8 \pm 0.2 \text{ parsec.}$$

The resulting sum of masses and mass for component A from the discussed orbits are listed in Table 3.

Due the possible high mass sum described by Pribulla (2001), he assumed on basis of Soederhjelms orbit, 44 Boötis A is possibly itself a binary. With the new orbit the sum of masses was clearly reduced.

Adapted from Schmidt-Kaler (1982) tables for physical parameters of main sequence stars, with the derived absolute magnitude 4,6 mag and the spectral class of an early G-Star (G0 - G2 V), a theoretical mass of 1,0 - 1,1 Msol is adopted. The calculated mass 1.04 ± 0.10 M_{sol} supports my assumption that component A is a simple, normal main sequence star.

Acknowledgements

Andreas Alzner, played a crucial role in my interest in the calculation and publication of orbits. This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory, the NASA Astrophysics Data System Bibliographic Services and the SIMBAD database (operated at CDS, Strasbourg, France).

Table 3: 44 Boötis, sum of masses and mass for component A

	Zirm 2010	Heintz 1997	Soederhjelm 1999
ΣM	2.32	2.17	2.69
σΣM	±0.12	>±0.08	>±0.10
		no information about uncertainty in a and P available	
M_A	1.04	0.89	1.41
σM_A	±0.10	>±0.06	>±0.08

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Appendix

A total of 799 measures up to mid 2009 are available, collected and transformed in weighted yearly normal points: 175 normal points for the class of visual measurements, 23 for photographic and CCD and 29 for speckle normal points. Due to large errors or insufficient measurements 11 single measurements were not used.

Table 4: 44 Boötis, normal points for each observation class and residuals, compared with the recent orbits

					Weights		Zirm 2010		Heintz 1997		Soederhjelm 1999	
Date	ϑ°_{2000}	ρ"	Reference/Nights	Class	Wi ϑ"	Wi ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"
1781.620	60.1	1.500	H__1	Visual	0.06	0.02	9.8	-0.21	4.4	-0.70	14.2	0.07
1802.250	63.0		H__1	Visual	0.00	0.00	-0.7		-7.8		3.5	
1819.430	228.0	1.500	StF1	Visual	0.21	0.07	-0.1	0.13	-1.0	-0.05	1.1	0.41
1821.330	229.1	2.280	SHJ1	Visual	0.07	0.02	-0.9	0.63	-1.4	0.49	-0.5	0.87
1826.790	231.0	2.230	StF1	Visual	2.19	0.73	-2.0	-0.13	-2.2	-0.20	-2.3	-0.01
1829.200	233.6	2.560	StF2	Visual	2.76	0.92	-0.3	-0.08	-0.4	-0.13	-0.6	0.00
1830.497	234.6	2.974	HJ_3 Smy1	Visual	8.77	2.92	0.3	0.19	0.2	0.16	0.0	0.25
1831.507	234.1	3.004	HJ_4 Smy1 Da_8	Visual	8.74	2.91	-0.4	0.11	-0.5	0.09	-0.8	0.16
1832.565	234.4	2.964	StF12 HJ_1 Da_4	Visual	11.80	3.93	-0.4	-0.03	-0.5	-0.05	-0.8	0.00
1833.250	235.0	3.060	HJ_1	Visual	1.96	0.65	0.0	-0.01	0.0	-0.02	-0.4	0.02
1834.557	235.2	3.300	Smy1 Da_2	Visual	3.00	1.00	-0.1	0.11	-0.1	0.10	-0.5	0.12
1835.511	235.3	3.270	Mad2 StF6 Da_2	Visual	10.53	3.51	-0.1	-0.01	-0.2	-0.01	-0.6	0.00
1836.551	235.1	3.541	Mad4 Da_1 StF4 Smy1	Visual	12.22	4.07	-0.6	0.17	-0.6	0.17	-1.0	0.17
1837.750	236.0	3.390	StF4	Visual	4.34	1.45	0.1	-0.08	0.1	-0.07	-0.3	-0.10
1839.620	235.3	3.500	Smy1	Visual	2.49	0.83	-0.9	-0.12	-1.0	-0.11	-1.3	-0.15
1840.760	235.2	3.660	Stt5	Visual	6.26	2.09	-1.2	-0.05	-1.2	-0.03	-1.6	-0.09
1841.408	236.0	3.765	Da_11 Gsh1 Mad3 Kai6	Visual	16.34	5.45	-0.5	0.01	-0.5	0.03	-0.9	-0.03
1842.712	236.5	3.816	Smy1 Da_1 Mad2	Visual	9.54	3.18	-0.2	-0.04	-0.2	-0.01	-0.5	-0.08
1843.626	236.9	3.829	Mad6 Kai9	Visual	11.45	3.82	0.1	-0.08	0.0	-0.06	-0.3	-0.14
1845.513	237.1	4.100	Mad5	Visual	6.27	2.09	0.0	0.07	0.0	0.10	-0.3	0.01
1846.180	236.5	4.220	Jc_2	Visual	2.79	0.93	-0.6	0.15	-0.7	0.18	-1.0	0.08
1847.423	237.0	3.915	Hin2 Mad1 Smy1 Mtl1	Visual	11.59	3.86	-0.3	-0.23	-0.4	-0.20	-0.6	-0.30
1848.481	237.6	4.253	Stt3 Da_3 BdW2 BdG1	Visual	21.86	7.29	0.2	0.05	0.1	0.08	-0.2	-0.02
1849.480	237.3	4.360	Da_1	Visual	3.10	1.03	-0.2	0.10	-0.3	0.14	-0.6	0.03
1851.656	237.8	4.430	Flt4 Da_1 Mad9	Visual	14.84	4.95	0.0	0.07	0.0	0.10	-0.3	-0.01
1852.650	237.9	4.250	Mad15	Visual	10.12	3.37	0.0	-0.16	-0.1	-0.12	-0.3	-0.24
1853.345	238.0	4.309	Stt2 Jc_2 Flt1 MiJ5 Mad7 Pwl8	Visual	24.60	8.20	0.0	-0.13	0.0	-0.09	-0.3	-0.21
1854.570	239.0	4.481	Mrt2 D__11 Da_1	Visual	14.79	4.93	0.9	-0.01	0.8	0.03	0.6	-0.09
1855.245	238.4	4.405	D__2 Mad3 Pwl2	Visual	9.21	3.07	0.2	-0.11	0.2	-0.08	-0.1	-0.20
1856.576	238.0	4.575	Se_7 D__5 Stt4	Visual	19.35	6.45	-0.3	0.01	-0.4	0.05	-0.6	-0.08

Table continues on next page.

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Table 4, continued: 44 Boötis, normal points for each observation class and residuals, compared with the recent orbits

					Weights		Zirm 2010		Heintz 1997		Soederhjelm 1999	
Date	**ϑ°$_{2000}$**	**ρ"**	**Reference/Nights**	**Class**	**Wi ϑ"**	**Wi ρ"**	**O-C ϑ°**	**O-C ρ"**	**O-C ϑ°**	**O-C ρ"**	**O-C ϑ°**	**O-C ρ"**
1858.560	237.6	4.680	D__4 Mad2	Visual	9.45	3.15	-0.9	0.05	-1.0	0.08	-1.2	-0.04
1861.290	238.8	5.040	Pwl5	Visual	4.84	1.61	0.0	0.33	0.0	0.36	-0.2	0.24
1862.420	238.1	4.610	Mai1	Visual	3.92	1.31	-0.8	-0.13	-0.8	-0.10	-1.0	-0.22
1863.388	237.8	4.717	D__6 Stt7	Visual	15.05	5.02	-1.2	-0.05	-1.2	-0.01	-1.4	-0.13
1864.670	240.6	4.500	Eng1	Visual	3.83	1.28	1.5	-0.29	1.5	-0.26	1.3	-0.38
1865.375	239.5	4.711	Eng4 D__12 Flt1	Visual	16.91	5.64	0.4	-0.09	0.3	-0.06	0.1	-0.18
1866.586	240.3	4.776	Se_1 Sea1	Visual	10.94	3.65	1.0	-0.05	1.0	-0.02	0.8	-0.14
1867.379	237.7	4.720	Win2 Tal2	Visual	6.75	2.25	-1.6	-0.12	-1.7	-0.09	-1.9	-0.20
1869.372	239.2	4.762	Du_10 Mai2 D__5	Visual	19.10	6.37	-0.3	-0.10	-0.4	-0.07	-0.5	-0.19
1870.320	240.0	4.690	Gld1	Visual	4.31	1.44	0.4	-0.18	0.4	-0.16	0.2	-0.27
1871.463	240.0	4.808	Gld4 Du_14 Pei1 Tal1 WS_4 Brn1	Visual	36.06	12.02	0.3	-0.08	0.3	-0.05	0.1	-0.16
1872.191	238.8	4.887	Stt2 Brn1	Visual	11.68	3.89	-0.9	0.00	-1.0	0.02	-1.2	-0.09
1873.113	240.4	5.058	D__6 WS_3	Visual	11.79	3.93	0.6	0.16	0.5	0.19	0.3	0.08
1874.144	238.9	4.608	Tal2 Gld11	Visual	13.82	4.61	-1.0	-0.29	-1.1	-0.27	-1.2	-0.37
1875.442	240.2	4.778	Mai1 Stt1 Du_4	Visual	16.44	5.48	0.2	-0.13	0.1	-0.10	-0.1	-0.21
1876.322	240.2	4.944	Sp_6 Dob4 Hl_2	Visual	18.98	6.33	0.1	0.04	0.0	0.06	-0.1	-0.04
1877.281	240.0	5.011	Plm7 Dob5 Fla1 Je_8	Visual	19.64	6.55	-0.2	0.11	-0.2	0.13	-0.4	0.03
1878.482	240.7	4.981	WJM7 Smt2 Dob3	Visual	19.03	6.34	0.4	0.08	0.4	0.10	0.2	0.00
1879.488	240.5	4.898	Sp_6 Hod4 Sbk6 Prc2 Je_3	Visual	33.31	11.10	0.1	0.00	0.1	0.02	-0.1	-0.08
1880.379	240.7	4.930	Dob3 Je_3	Visual	11.29	3.76	0.2	0.04	0.2	0.05	0.0	-0.04
1881.365	241.4	4.837	Sp_5 Big1 Hl_2 Prt2 Prc2	Visual	33.52	11.17	0.9	-0.05	0.8	-0.03	0.7	-0.12
1882.489	240.8	4.904	Hl_4 Sbk6 Frs3 Sp_5 Stt1 Je_5	Visual	45.41	15.14	0.2	0.02	0.1	0.04	0.0	-0.05
1883.471	240.4	4.869	Eng6 Frs3 Sp_5 Hl_3 Per2 Ku_5	Visual	47.52	15.84	-0.3	0.00	-0.4	0.01	-0.5	-0.07
1884.453	241.4	4.889	Nst1 Hl_3 Sp_4	Visual	19.95	6.65	0.6	0.03	0.5	0.04	0.4	-0.04
1885.444	240.9	4.982	Hl_3 Per3 Smt1 Sp_4 Je_3	Visual	33.08	11.03	0.0	0.13	-0.1	0.15	-0.2	0.07
1886.473	241.7	4.843	Hl_3 Smt2	Visual	15.01	5.00	0.7	0.01	0.7	0.02	0.5	-0.06
1887.527	241.0	4.850	Tar2 Cel4 Sp_6	Visual	20.81	6.94	-0.1	0.03	-0.1	0.04	-0.3	-0.03
1888.581	240.6	4.825	Glp2 Hl_3 Cel2 Sp_5 Stt3	Visual	34.88	11.63	-0.6	0.02	-0.6	0.04	-0.8	-0.04
1889.518	241.9	4.767	SBc2 Hl_3 Maw2	Visual	18.97	6.32	0.6	-0.02	0.6	-0.01	0.5	-0.08
1890.481	241.5	4.812	Glp2 Hl_3 Nst1 Cel1	Visual	21.75	7.25	0.1	0.05	0.1	0.06	0.0	-0.01
1891.482	241.6	4.844	Hl_3 See4 Sp_4	Visual	34.05	11.35	0.2	0.10	0.1	0.11	0.0	0.04
1892.486	241.4	4.852	Lv_2 Sea3 Com2	Visual	18.78	6.26	-0.1	0.13	-0.2	0.14	-0.3	0.07
1893.398	241.5	4.794	Jns2 Cls2 Big7	Visual	18.60	6.20	-0.1	0.09	-0.2	0.10	-0.3	0.04
1894.560	242.7	4.790	Ebl1	Visual	4.69	1.56	1.0	0.11	0.9	0.12	0.8	0.06
1895.313	241.0	4.789	Ren8 Glp2 Cls2 Com3	Visual	33.00	11.00	-0.8	0.13	-0.9	0.14	-1.0	0.08
1896.486	242.2	4.738	Lv_2 Nst1 Hu_4 Eic3	Visual	21.46	7.15	0.3	0.11	0.2	0.12	0.1	0.06
1897.539	241.9	4.506	Vil3 Col3	Visual	10.36	3.45	-0.1	-0.09	-0.2	-0.09	-0.3	-0.14
1898.412	241.7	4.649	Hu_1 Col4 Coh1	Visual	16.04	5.35	-0.4	0.08	-0.5	0.08	-0.6	0.03
1899.582	243.0	4.646	See2 Maw2	Visual	10.08	3.36	0.8	0.11	0.7	0.11	0.6	0.06
1900.407	242.2	4.517	Doo3 Loh2 Bog3 Dob2	Visual	24.93	8.31	-0.1	0.01	-0.2	0.01	-0.3	-0.04
1901.463	243.6	4.466	Loh1 Es_4 Bow1	Visual	18.09	6.03	1.2	-0.01	1.1	-0.01	1.0	-0.05
1902.520	242.6	4.800	Pos1	Visual	5.66	1.89	0.1	0.36	0.0	0.36	-0.1	0.32
1903.322	241.6	4.444	VBs2 Dob2 L__1	Visual	21.42	7.14	-1.0	0.03	-1.1	0.03	-1.2	-0.01

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The Rapid Convergence of 44 Boötis with Revised Orbit and Updated Ephemerides

Table 4, continued: 44 Boötis, normal points for each observation class and residuals, compared with the recent orbits

					Weights		Zirm 2010		Heintz 1997		Soederhjelm 1999	
Date	$\vartheta°_{2000}$	ρ"	Reference/Nights	Class	Wi ϑ"	Wi ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"
1904.518	244.7	4.279	Loh1 Frm1	Visual	8.43	2.81	1.9	-0.09	1.9	-0.09	1.8	-0.13
1905.333	243.5	4.275	Bu_4 L__1 Bow1 Lau2	Visual	34.71	11.57	0.7	-0.06	0.6	-0.06	0.5	-0.10
1906.451	243.2	4.416	A__2 L__2	Visual	20.80	6.93	0.2	0.12	0.2	0.12	0.1	0.08
1907.462	242.6	4.100	VBs3	Visual	6.19	2.06	-0.5	-0.16	-0.5	-0.16	-0.6	-0.19
1908.373	243.2	4.251	VBs2 Lau1 Jan1 Bu_4 Fox3 Dob3 Prz4 L__1 Has6	Visual	49.82	16.61	0.0	0.03	0.0	0.03	-0.1	-0.01
1909.429	243.3	4.179	VBs3 Phl2 J__3 Dob4 Doo3 Lau3	Visual	33.72	11.24	0.0	0.00	0.0	0.00	-0.1	-0.03
1910.576	244.5	4.184	Lau1 Dob3 VBs3 Gut2 Fur2	Visual	32.55	10.85	1.0	0.06	1.0	0.06	0.9	0.02
1911.448	243.4	4.067	VBs3 Dob3 Vou4 Es_3 Fox3 L__1 Jan1	Visual	34.69	11.56	-0.2	-0.02	-0.2	-0.02	-0.3	-0.06
1912.434	243.7	4.077	Neu3 Vou4 Dob2 Fes1	Visual	19.24	6.41	0.0	0.03	0.0	0.03	-0.1	0.00
1913.480	244.1	3.970	Vou6 Sla3 Lv_1 VBs3 WFD1	Visual	19.10	6.37	0.3	-0.03	0.2	-0.03	0.2	-0.06
1914.407	244.7	4.018	Vys3 Rab7 Phl3 Chp1	Visual	24.39	8.13	0.7	0.06	0.7	0.06	0.6	0.03
1915.356	244.7	3.914	Dob3 Rab12 Frk3 Com2	Visual	17.85	5.95	0.6	0.00	0.6	0.00	0.5	-0.03
1916.340	245.0	3.814	VBs3 Rab10 Com3	Visual	23.42	7.81	0.8	-0.05	0.8	-0.05	0.7	-0.08
1917.474	244.4	3.875	Com3 J__2	Visual	14.45	4.82	0.0	0.07	0.0	0.07	-0.1	0.04
1918.480	243.9	3.770	Com3	Visual	5.92	1.97	-0.7	0.01	-0.7	0.01	-0.7	-0.01
1919.492	243.9	3.739	Com3 Lv_3	Visual	10.28	3.43	-0.8	0.03	-0.8	0.04	-0.9	0.01
1920.463	244.5	3.717	Dob3 Pav2 Cha4 Kpz4	Visual	21.56	7.19	-0.4	0.06	-0.4	0.06	-0.4	0.04
1921.459	244.9	3.588	Lbz2 VBs3 Prz4 Btz1 B__3	Visual	31.25	10.42	-0.1	-0.01	-0.1	-0.01	-0.2	-0.04
1922.501	245.0	3.600	Nec1 B__4 Lv_1 Dic5 Lbz1 Prz3 StG3 Pek3	Visual	38.34	12.78	-0.2	0.06	-0.2	0.06	-0.3	0.03
1923.469	245.0	3.551	Fur3 B__4 VBs2 Dic2 Rou2 Lv_3 Lbz2 Prz5 StG2	Visual	54.01	18.00	-0.4	0.06	-0.4	0.06	-0.4	0.04
1924.478	245.2	3.389	StG1 B__4 Dob4 Jan2 Fat2 Lv_2 Wtl1 VBs3	Visual	42.36	14.12	-0.3	-0.04	-0.3	-0.04	-0.4	-0.07
1925.445	245.9	3.377	B__4 Dob4 VBs3 StG4 Baz4 Lv_4 Ber6	Visual	37.08	12.36	0.2	0.00	0.2	0.00	0.1	-0.02
1926.455	245.9	3.183	VBs3 Lv_6 Ber6	Visual	18.40	6.13	0.0	-0.14	0.0	-0.13	-0.1	-0.16
1927.516	245.4	3.339	Rab4 Kom5 StG4 Baz2	Visual	19.27	6.42	-0.7	0.08	-0.7	0.08	-0.8	0.06
1928.443	246.4	3.348	Kom3 Buc5 Bea4	Visual	13.53	4.51	0.1	0.15	0.1	0.15	0.0	0.12
1929.255	246.3	3.170	VBs3 All2 Kom3	Visual	16.07	5.36	-0.2	0.02	-0.2	0.02	-0.2	0.00
1930.502	246.6	3.070	Kui4 Dob3 All1 Kom4 StG3 Baz19	Visual	28.37	9.46	-0.2	-0.01	-0.2	0.00	-0.2	-0.03
1931.455	247.1	2.901	VBs3 StG4 Smw6 All1 Kom4 Bon4	Visual	30.92	10.31	0.1	-0.11	0.1	-0.11	0.1	-0.14
1932.433	247.0	2.890	VBs2 Smw4 Kom3 StG4 Smw19 Rab5	Visual	38.78	12.93	-0.2	-0.06	-0.2	-0.06	-0.3	-0.09
1933.572	248.0	2.801	Baz4 Rab5	Visual	6.89	2.30	0.5	-0.08	0.5	-0.08	0.5	-0.10
1934.377	247.7	2.934	Rab10 Kui1 Dob4 Pok2	Visual	15.08	5.03	0.0	0.11	0.0	0.11	0.0	0.08

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The Rapid Convergence of 44 Boötis with Revised Orbit and Updated Ephemerides

Table 4, continued: 44 Boötis, normal points for each observation class and residuals, compared with the recent orbits

					Weights		Zirm 2010		Heintz 1997		Soederhjelm 1999	
Date	$\vartheta°_{2000}$	ρ"	Reference/Nights	Class	Wi ϑ"	Wi ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"
1935.161	249.0	2.702	Baz4 Rab6	Visual	4.84	1.61	1.0	-0.08	1.1	-0.07	1.0	-0.10
1936.396	250.5	2.778	Dur3 Rab6	Visual	3.94	1.31	2.2	0.08	2.2	0.09	2.2	0.06
1937.305	248.9	2.599	Baz4 Mlr4 Str5 Phl3 Rab9 Dur4	Visual	17.31	5.77	0.3	-0.04	0.3	-0.03	0.3	-0.06
1938.417	248.4	2.573	Mlr1 Str4 Woy5 Dur9 Mlr6 Rab8 Phl3	Visual	20.69	6.90	-0.6	0.01	-0.5	0.02	-0.5	-0.01
1939.446	249.2	2.433	Baz6 Mlr5 Scd5 Sem4 Woy3 Rab9 Dur13 Sem2 VBs4	Visual	36.20	12.07	-0.1	-0.06	-0.1	-0.05	-0.1	-0.08
1940.421	249.9	2.420	Kor4 Dur1 Rab9	Visual	13.09	4.36	0.2	0.00	0.3	0.01	0.3	-0.02
1941.430	250.5	2.264	Baz5 VBs5 Rab10 Sem4 Dur5	Visual	21.62	7.21	0.4	-0.09	0.5	-0.08	0.5	-0.11
1942.466	251.0	2.298	Ahn5 Dur10 Rab11	Visual	11.72	3.91	0.5	0.02	0.6	0.03	0.6	0.00
1943.381	251.8	2.122	Baz5 VBs1 Dur16 Rab9	Visual	20.35	6.78	0.9	-0.09	1.0	-0.08	1.0	-0.11
1944.387	252.7	2.058	VBs6 Dur12 Rab5	Visual	21.18	7.06	1.3	-0.08	1.4	-0.07	1.5	-0.11
1945.347	253.2	2.011	Baz5 VBs4 Arm2 Dur5	Visual	20.13	6.71	1.4	-0.06	1.4	-0.05	1.5	-0.08
1946.508	252.3	1.982	Mlr5 Rab5	Visual	4.94	1.65	-0.2	0.00	-0.1	0.01	0.0	-0.03
1947.305	252.3	2.002	Baz5 Mlr5 Mun3	Visual	7.91	2.64	-0.6	0.08	-0.5	0.09	-0.4	0.05
1948.478	253.9	1.831	Mlr3 Fok4 Rab7 Baz2 VBs2	Visual	14.12	4.71	0.3	-0.01	0.3	0.00	0.4	-0.04
1949.349	255.3	1.677	VBs4 Rab7 Baz2	Visual	9.91	3.30	1.1	-0.10	1.2	-0.09	1.3	-0.13
1950.379	255.8	1.634	VBs4 Mlr3 Rab10 Guy4	Visual	9.92	3.31	0.8	-0.06	0.9	-0.05	1.1	-0.09
1951.465	255.3	1.614	Mlr4 Pre1 Rab11 WRH2 Baz4	Visual	12.12	4.04	-0.6	0.00	-0.5	0.01	-0.3	-0.03
1952.381	256.2	1.485	VBs4 Mlr2 Pre1 Rab12	Visual	13.38	4.46	-0.5	-0.06	-0.4	-0.05	-0.1	-0.09
1953.468	258.1	1.404	Mlr3 Dju3 Rab9 Ces3 Baz4 VBs6	Visual	16.58	5.53	0.4	-0.06	0.4	-0.05	0.7	-0.09
1954.362	257.9	1.366	Guy2 Mlr5 Wie2 Rab7 Baz4	Visual	7.20	2.40	-0.8	-0.03	-0.7	-0.02	-0.4	-0.06
1955.394	258.9	1.307	Wor4 Mlr7 Cou3 Br_4 Baz5 Rab7 Fle5	Visual	12.36	4.12	-1.0	-0.01	-1.0	0.00	-0.6	-0.04
1956.373	261.7	1.222	VBs4 Mlr6 Br_3 Wor3 Rab4 Baz4	Visual	14.73	4.91	0.4	-0.02	0.5	-0.01	1.0	-0.05
1957.473	262.5	1.194	Sgt4 Mlr6 Clu3 Br_3 VBs6 Cou4 Dju4 Dic1 Hnz4 Pau4 Rab6 B__3	Visual	30.76	10.25	-0.4	0.03	-0.4	0.05	0.2	0.00
1958.476	264.3	1.116	Cou3 B__6 Wor3 VBs4 Clu3	Visual	14.80	4.93	-0.4	0.03	-0.4	0.04	0.4	0.00
1959.423	266.0	1.093	Hg_2 Cdy4 Dic1 Hnz3 Pau5 Sgt6 Wor4 Woy13	Visual	12.94	4.31	-0.6	0.08	-0.6	0.09	0.3	0.04
1960.465	269.2	0.958	Cou3 Dic1 Pau5 Hnz4 You3 Hei5 VBs7	Visual	12.26	4.09	0.1	0.02	0.1	0.03	1.2	-0.01
1961.591	272.4	0.886	Wor4 Cdy3 Woy3 Cou2 B__4 VBs12	Visual	8.91	2.97	0.2	0.03	0.1	0.04	1.6	0.00
1962.425	274.8	0.854	B__4 Wor4 Cou3 Pau2 Hei4 Hnz1 Lan1 Baz4	Visual	13.17	4.39	-0.1	0.06	-0.2	0.07	1.5	0.02
1963.371	279.0	0.720	VBs5 Wor3 Dur9 Hei6 B__6 Cou3 Pau3 Hnz4	Visual	11.53	3.84	0.5	-0.01	0.3	0.00	2.4	-0.05

Table continues on next page.

The Rapid Convergence of 44 Boötis with Revised Orbit and Updated Ephemerides

Table 4, continued: 44 Boötis, normal points for each observation class and residuals, compared with the recent orbits

					Weights		Zirm 2010		Heintz 1997		Soederhjelm 1999	
Date	ϑ°2000	ρ"	Reference/Nights	Class	Wi ϑ"	Wi ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"
1964.445	283.1	0.677	Cdy5 Wor4 Cou2 Sym8 Dju2 Pop2 Baz4	Visual	7.07	2.36	-0.3	0.01	-0.6	0.03	2.1	-0.02
1965.305	287.7	0.642	VBs8 Dur13 Cdy5 Sle3 Wor4 Dju3 Hei4	Visual	7.00	2.33	-0.4	0.03	-0.9	0.04	2.5	0.00
1966.334	294.9	0.571	Dur5 VBs8 Wak4 Wor9 Sym3 Mlr4 Baz2	Visual	10.06	3.35	0.1	0.01	-0.6	0.03	3.7	-0.01
1967.388	302.0	0.534	Dur5 Wor6 Wak3 Sym5 Baz4 VBs2 Srb3	Visual	5.44	1.81	-1.0	0.02	-2.0	0.04	3.4	0.00
1968.404	312.1	0.506	VBs6 Wor8 Wak3 Dur5	Visual	7.88	2.63	-0.2	0.03	-1.6	0.04	5.0	0.01
1969.419	324.1	0.479	Wor4 Cou2 Baz4	Visual	2.67	0.89	1.3	0.02	-0.3	0.03	7.2	0.01
1970.455	334.8	0.508	Wor6 Ary3 Wak2 Dur4	Visual	1.47	0.49	0.8	0.06	-1.0	0.06	7.0	0.05
1971.492	346.2	0.515	Cou2 Wor2 Dur1	Visual	1.50	0.50	1.1	0.05	-0.7	0.05	7.3	0.06
1972.381	355.9	0.480	Wor4 Dur5	Visual	2.16	0.72	2.1	-0.01	0.4	-0.01	7.9	0.01
1973.455	3.4	0.561	Dur6 Wie1 Hei4 Wor4 Hln4	Visual	3.95	1.32	0.3	0.03	-1.2	0.03	5.5	0.06
1974.395	10.1	0.584	Dur3 Wor4 Cou2 Beh3	Visual	4.02	1.34	0.1	0.01	-1.2	0.00	4.7	0.04
1975.398	16.5	0.611	Ole1 Hei4 Wor4 Wie4 Wak2 Beh1	Visual	4.53	1.51	0.4	-0.02	-0.8	-0.03	4.3	0.01
1976.450	21.6	0.725	Wor3 Wie4 Wak2	Visual	2.10	0.70	0.2	0.03	-0.8	0.02	3.5	0.07
1977.343	25.6	0.839	Hei3 Wor3 Wie2	Visual	2.32	0.77	0.4	0.08	-0.4	0.08	3.3	0.13
1978.488	30.1	0.849	Wie4 Hln2 Wor4	Visual	4.60	1.53	0.8	0.02	0.2	0.01	3.3	0.06
1979.460	33.8	0.920	Wor3	Visual	1.98	0.66	1.7	0.02	1.1	0.01	3.8	0.07
1980.418	35.5	1.007	Cll3 Wor2 Hei3	Visual	4.88	1.63	0.9	0.04	0.4	0.03	2.8	0.09
1982.416	38.7	1.240	Wor4 Ary2 Wie3 Mss3	Visual	6.15	2.05	0.0	0.13	-0.3	0.11	1.6	0.18
1985.531	45.6	1.382	Wie2 Wor3	Visual	3.12	1.04	2.3	0.05	2.1	0.03	3.4	0.10
1986.437	44.9	1.462	Tob1 Stu3 Sca1 Wor5	Visual	5.67	1.89	0.5	0.07	0.4	0.05	1.6	0.12
1987.350	45.6	1.660	Doc2	Visual	2.34	0.78	0.2	0.20	0.1	0.18	1.2	0.25
1988.434	46.1	1.600	Stu5 Wie1 Gel5	Visual	4.53	1.51	-0.4	0.07	-0.4	0.05	0.6	0.12
1989.750	49.4	1.628	Stu4 Gir1 Wor4	Visual	5.00	1.67	1.8	0.02	1.8	-0.01	2.7	0.06
1990.356	48.0	1.589	Tob1 Kzn5 Ary4	Visual	2.91	0.97	-0.1	-0.06	-0.1	-0.09	0.7	-0.01
1991.620	49.7	1.780	Ary3	Visual	0.94	0.31	0.6	0.06	0.7	0.02	1.4	0.10
1992.459	49.9	1.799	Tob2 Stu4 Kzn5 Ary5	Visual	5.41	1.80	0.2	0.03	0.3	-0.01	1.0	0.07
1993.463	49.6	1.842	Stu3 Kzn4 Ary4	Visual	3.21	1.07	-0.8	0.02	-0.6	-0.03	0.0	0.06
1994.576	52.0	1.916	Tob2 Ary4 WFD4	Visual	4.22	1.41	0.8	0.05	1.1	-0.01	1.6	0.08
1995.471	51.2	1.853	Tob3 Doc3 Ary4	Visual	6.87	2.29	-0.5	-0.05	-0.2	-0.12	0.3	-0.02
1996.498	52.7	1.951	Ctt4 Hei3 Kzn3 Ary4	Visual	9.09	3.03	0.4	0.01	0.7	-0.07	1.1	0.03
1997.465	52.7	1.926	Alz4 Kzn3 Ary5	Visual	9.61	3.20	-0.2	-0.05	0.2	-0.14	0.6	-0.03
1998.519	53.4	1.962	Alz2 Tob1 Ary5	Visual	4.85	1.62	-0.1	-0.04	0.4	-0.15	0.7	-0.02
1999.456	54.4	2.021	Alz3 Tob1 Tob1 Ary5	Visual	6.33	2.11	0.4	0.01	1.0	-0.12	1.2	0.02
2000.452	54.5	2.046	Alz4 Ary5	Visual	4.32	1.44	0.0	0.02	0.6	-0.13	0.7	0.03
2001.459	55.1	2.027	Alz4 Ary5	Visual	5.53	1.84	0.1	0.00	0.7	-0.17	0.8	0.00
2002.499	55.3	2.034	Alz4 Ary5	Visual	5.55	1.85	-0.3	0.02	0.5	-0.18	0.4	0.01
2003.490	56.7	1.989	Alz2 Ary4	Visual	4.83	1.61	0.6	-0.01	1.4	-0.24	1.3	-0.02
2004.495	56.7	1.934	Alz2 Ary3	Visual	4.51	1.50	0.0	-0.04	1.0	-0.30	0.8	-0.05

Table continues on next page.

The Rapid Convergence of 44 Boötis with Revised Orbit and Updated Ephemerides

Table 4, continued: 44 Boötis, normal points for each observation class and residuals, compared with the recent orbits

					Weights		Zirm 2010		Heintz 1997		Soederhjelm 1999	
Date	$\vartheta°_{2000}$	ρ"	Reference/Nights	Class	Wi ϑ"	Wi ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"	O-C ϑ°	O-C ρ"
2005.455	57.7	1.902	Alz3 Ary5	Visual	5.00	1.67	0.4	-0.03	1.6	-0.33	1.2	-0.05
2006.507	57.6	1.836	Alz3 Ary6	Visual	5.01	1.67	-0.3	-0.04	1.0	-0.39	0.5	-0.06
2007.494	59.2	1.835	Alz2 Ary6	Visual	4.83	1.61	0.7	0.02	2.2	-0.37	1.5	0.00
2008.548	60.4	1.680	Ary4	Visual	1.93	0.64	1.1	-0.06	2.9	-0.50	2.0	-0.07
1889.520	241.2	4.700	Kin1	Phot+CCD	4.70	4.70	-0.1	-0.084	-0.1	-0.074	-0.2	-0.144
1904.270	243.4	4.360	Thi1	Phot+CCD	4.36	4.36	0.7	-0.019	0.6	-0.016	0.5	-0.059
1915.322	243.9	3.909	Hzg7	Phot+CCD	7.82	7.82	-0.2	-0.004	-0.2	-0.003	-0.3	-0.033
1919.356	244.7	3.712	Hzg2	Phot+CCD	7.42	7.42	0.0	0.001	0.0	0.001	-0.1	-0.026
1922.437	245.0	3.540	Mch1	Phot+CCD	7.08	7.08	-0.2	-0.007	-0.2	-0.006	-0.2	-0.032
1926.464	246.1	3.301	Mch2 Lbz1	Phot+CCD	16.51	16.51	0.2	-0.017	0.2	-0.016	0.1	-0.041
1930.320	246.8	3.170	Reu2	Phot+CCD	6.34	6.34	0.1	0.084	0.1	0.086	0.0	0.061
1938.310	248.9	2.555	Jef2	Phot+CCD	10.22	10.22	0.0	-0.011	0.0	-0.006	0.0	-0.034
1941.490	250.0	2.306	Str1	Phot+CCD	4.61	4.61	-0.1	-0.040	0.0	-0.033	0.0	-0.063
1949.184	254.2	1.747	DeO2	Phot+CCD	6.99	6.99	0.1	-0.040	0.2	-0.029	0.3	-0.067
1951.483	255.6	1.567	Jef1	Phot+CCD	3.13	3.13	-0.3	-0.048	-0.2	-0.036	0.0	-0.076
1953.502	257.3	1.417	Jef1	Phot+CCD	2.83	2.83	-0.5	-0.045	-0.4	-0.032	-0.1	-0.075
1954.292	258.1	1.320	Jef1	Phot+CCD	2.64	2.64	-0.5	-0.082	-0.4	-0.069	-0.1	-0.112
1955.209	260.0	1.294	Jef1	Phot+CCD	2.59	2.59	0.3	-0.038	0.4	-0.025	0.8	-0.069
1957.190	261.9	1.089	Gzl1	Phot+CCD	1.09	1.09	-0.6	-0.093	-0.5	-0.079	0.0	-0.125
1997.660	53.9	2.000	ADP10	Phot+CCD	4.00	4.00	0.9	0.021	1.3	-0.076	1.7	0.042
2003.366	55.8	1.995	Izm8	Phot+CCD	7.98	7.98	-0.3	-0.008	0.6	-0.233	0.5	-0.015
2004.234	55.9	1.971	Izm7	Phot+CCD	7.88	7.88	-0.7	-0.009	0.3	-0.263	0.1	-0.020
2005.180	56.9	1.945	Izm4	Phot+CCD	7.78	7.78	-0.2	-0.001	0.9	-0.290	0.6	-0.014
2006.241	57.4	1.897	Izm5	Phot+CCD	7.59	7.59	-0.3	0.001	0.9	-0.331	0.5	-0.013
2007.401	57.9	1.816	Izm6 WSI2 Smr1	Phot+CCD	16.34	16.34	-0.6	-0.009	0.9	-0.394	0.2	-0.022
2008.333	58.3	1.723	Ant2 Smr1	Phot+CCD	5.17	5.17	-0.8	-0.033	0.9	-0.465	0.0	-0.043
2009.347	60.4	1.680	Ant1 Smr1	Phot+CCD	3.36	3.36	0.5	0.010	2.5	-0.475	1.4	0.006
1976.241	21.2	0.684	McA5	Speckle	11.63	11.63	0.7	0.001	-0.3	-0.006	4.2	0.039
1977.136	24.7	0.745	McA2	Speckle	3.73	3.73	0.3	0.004	-0.6	-0.004	3.3	0.045
1978.183	29.1	0.813	McA2	Speckle	4.07	4.07	0.8	0.001	0.1	-0.008	3.4	0.045
1979.464	32.5	0.906	McA2 Tok1	Speckle	4.53	4.53	0.4	0.005	-0.2	-0.006	2.5	0.051
1980.318	35.0	0.977	McA2	Speckle	7.82	7.82	0.7	0.015	0.2	0.003	2.6	0.063
1981.459	36.2	1.056	Tok2 McA3	Speckle	13.73	13.73	-0.6	0.012	-1.1	-0.001	1.0	0.061
1982.428	37.3	1.106	McA3 Tok1	Speckle	4.42	4.42	-1.4	-0.008	-1.7	-0.021	0.1	0.042
1983.471	40.8	1.190	McA4	Speckle	11.90	11.90	0.4	0.001	0.1	-0.014	1.7	0.052
1984.316	42.0	1.251	McA7	Speckle	25.02	25.02	0.3	0.002	0.1	-0.014	1.6	0.053
1985.333	43.2	1.323	McA5	Speckle	15.88	15.88	0.1	0.003	0.0	-0.015	1.3	0.053
1986.362	44.4	1.394	McA6	Speckle	19.52	19.52	0.1	0.003	0.0	-0.017	1.2	0.053
1987.261	45.3	1.459	McA6	Speckle	17.51	17.51	0.0	0.007	-0.1	-0.015	1.0	0.056
1988.175	46.0	1.508	McA7	Speckle	24.13	24.13	-0.2	-0.004	0.3	-0.029	0.8	0.044
1989.224	47.2	1.589	McA3 Iso3	Speckle	14.62	14.62	0.0	0.010	0.0	-0.019	0.9	0.056
1991.381	48.3	1.696	HIP1 Hrt1 WSI7 TYC1	Speckle	23.74	23.74	-0.7	-0.012	-0.6	-0.050	0.2	0.031
1992.428	48.6	1.745	WSI2	Speckle	3.49	3.49	-1.1	-0.020	-1.0	-0.065	-0.3	0.020

Table continues on next page.

Table 4, concluded: 44 Boötis, normal points for each observation class and residuals, compared with the recent orbits

					Weights		Zirm 2010		Heintz 1997		Soederhjelm 1999	
Date	**$\vartheta°_{2000}$**	**ρ"**	**Reference/Nights**	**Class**	**Wi ϑ"**	**Wi ρ"**	**O-C ϑ°**	**O-C ρ"**	**O-C ϑ°**	**O-C ρ"**	**O-C ϑ°**	**O-C ρ"**
1993.479	49.2	1.790	WSI2	Speckle	3.58	3.58	-1.2	-0.029	-1.0	-0.080	-0.4	0.008
1994.414	49.8	1.852	WSI5	Speckle	9.26	9.26	-1.2	-0.010	-1.0	-0.070	-0.5	0.024
1995.150	51.6	1.885	Hrt1	Speckle	3.77	3.77	0.1	-0.009	0.4	-0.075	0.9	0.022
1996.477	51.7	1.967	WSI3	Speckle	5.90	5.90	-0.6	0.024	-0.3	-0.057	0.1	0.050
1997.145	51.9	1.965	Hrt1 TtB1	Speckle	4.32	4.32	-0.8	0.001	-0.4	-0.089	0.0	0.023
1998.413	53.3	1.960	WSI5	Speckle	9.80	9.80	-0.1	-0.037	0.4	-0.145	0.6	-0.020
1999.379	53.1	2.025	WSI2	Speckle	4.05	4.05	-0.8	0.011	-0.3	-0.114	-0.1	0.023
2000.409	55.1	2.000	WSI3	Speckle	2.00	2.00	0.6	-0.025	1.2	-0.171	1.3	-0.018
2001.443	55.8	2.030	WSI1 Hor2	Speckle	6.09	6.09	0.8	0.003	1.4	-0.167	1.5	0.005
2002.385	55.6	1.900	WSI1	Speckle	0.38	0.38	0.1	-0.120	0.8	-0.315	0.8	-0.122
2004.274	56.6	1.975	Doc1 WSI3	Speckle	3.95	3.95	0.0	-0.004	1.0	-0.259	0.8	-0.015
2005.427	57.1	1.935	WSI4 Sca1	Speckle	5.81	5.81	-0.1	-0.001	1.0	-0.299	0.6	-0.014
2006.320	58.1	1.900	WSI2	Speckle	1.90	1.90	0.3	0.009	1.6	-0.327	1.1	-0.006

The author is a mechanical engineer involved in research and development for laser direct imaging technologies. In addition to double stars, he also enjoys hiking.