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A METHODOLOGY FOR THE DESCRIPTION OF MULTIPLE STELLAR SYSTEMS WITH SPECTROSCOPIC SUBCOMPONENTS

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ABSTRACT

We propose a methodology for analyzing triple stellar systems that include a visual double star wherein one of the components is a single- or double-lined spectroscopic binary. By using this methodology, we can calculate the most probable values of the spectroscopic binary's inclination, the angular separation between its components, and its stellar masses, and we can even estimate the spectral types. For a few W UMa–type eclipsing binaries, stellar radii are also determined. Moreover, we present new formulae for calculating stellar masses depending on spectral type. In this way we have studied 61 triple systems, five of them W UMa–type eclipsing binaries with low-mass subcomponents. In addition, we study nine quadruple systems, applying the same methodology and considering them twice as a triple system. With the aim of having more accurate orbital elements, we have taken advantage of the occasion to calculate and improve orbits. In this way we have used a new speckle measurement to improve the orbital elements for the binary Hu 506 AB. Also, new visual orbits are calculated for the binaries BAG 10 Aa and LAB 6 Aa. Finally, we give a list of five spectroscopic binaries with more than 0.″1 for the maximum angular separation; these should be easily observable as visual binaries by means of interferometric techniques.

Subject headings: binaries: close — binaries: eclipsing — binaries: spectroscopic — binaries: visual — methods: data analysis — methods: statistical — stars: fundamental parameters

1. INTRODUCTION

It is well known that stellar systems of multiplicity three and higher are relatively frequent, about 20% of all stellar systems (Tokovinin 2004). Unfortunately, in most cases, our knowledge about their fundamental parameters is very poor.

Our aim is to study these stellar systems using several dynamical, photometric, and spectral data, along with the parallax. This last parameter, which plays an important role not only in the methodology that we present here but in astronomy in general, has been carefully cataloged for the nearby stars (trigonometric parallax) by successive authors belonging to the Yale University Observatory. In contrast, for more distant stars it was necessary to design efficient algorithms based on the magnitudes, spectral types, and orbital elements of binary stars (dynamical parallax), as in the methods of Russel & Moore (1940) and Baize & Romani (1946). Nowadays, the data provided by the astrometric satellite *Hipparcos* represent the most precise parallax values (Perryman et al. 1997).

We deal with a set of multiple stellar systems that consist of a visual binary wherein one of the components is a spectroscopic binary. Our methodology allows one to obtain, by using the two orbits and the *Hipparcos* parallax, the most probable values of the spectroscopic binary's inclination, the separation between its components, and the stellar masses of each component of the system, and even to estimate spectral types.

Our purpose is to determine for each triple (or quadruple) system a compatible set of physical and dynamical parameters. In this process, although it is not our aim to improve the *Hipparcos* parallax, we also obtain as secondary results a pair of parallax values (π_i and π_f), whose difference gives us a measure of the goodness of the results.

The remainder of this paper is structured as follows. We proceed by providing our notation and basic calculations of this methodology in § 2, where new formulae to calculate stellar masses depending on stellar types are also given. In § 3 we give a more detailed description of the methodology by its application to a triple system with a single-lined spectroscopic subcomponent. In § 4 we draw up a pair of tables with results for 61 triple systems and for nine quadruple systems. The goodness of the methodology is justified by the fact that for five (out of six) systems with known orbital elements, our results coincide within the margins of error. A relation for the minimum semimajor axis as function of eccentricity is also given in this section. Moreover, for five W UMa–type spectroscopic binaries (SBs) a particular analysis is made. In § 5 new orbits for three visual binaries (VBs) studied in this paper are given. We also propose a set of five SBs with probable maximum angular separations greater than 0.″1 to try to resolve them in § 6. Finally, in § 7 we discuss the usefulness of this methodology as well as its limitations.

2. METHODOLOGY

2.1. *Notation*

We use subscripts 1 and 2 to refer to spectroscopic subcomponents Aa and Ab, and subscript 3 to refer to distant star B (or Ba, Bb, and A), while the subscript 12 is used to refer to the spectroscopic subsystem. M_j is the absolute magnitude of the jth component, m_j is its apparent visual magnitude, and $\mathcal{M}_j$ is its mass. Lastly, ΔM is the difference between the absolute magnitudes of the spectroscopic subcomponents.

2.2. *Computation of Mean Parallax and Mean Magnitudes*

First, we take from the *Washington Double Star Catalog*[3] (Mason et al. 2001) the combined apparent magnitude of each

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[3] Available at http://ad.usno.navy.mil/wds/wds.html.

TABLE 1

Formulae for the Mass and Error Mass Calculations (in Solar Masses)

Relations	a	b	Spectral Range
$\mathcal{M}_{\rm III} = (a + b\,e^{-s})^2$, $\sigma(\mathcal{M}_{\rm III}) = 2\mathcal{M}_{\rm III}^{1/2}\sqrt{\sigma^2(a) + e^{-2s}\sigma^2(b)}$........	1.34 ± 0.17	20.8 ± 2.5	B4–K4
$\mathcal{M}_{\rm IV} = a\,s^b$, $\sigma(\mathcal{M}_{\rm IV}) = s^b\sqrt{\sigma^2(a) + a^2 \ln^2 s\,\sigma^2(b)}$......................	19.29 ± 0.86	-1.660 ± 0.065	B0.5–K3.5
$\mathcal{M}_{\rm V} = a + b/s^2$, $\sigma(\mathcal{M}_{\rm V}) = \sqrt{\sigma^2(a) + \sigma^2(b)/s^4}$...........................	-0.117 ± 0.090	27.47 ± 0.61	B0.5–M6

component of the visual pair (m_{12} and m_3). Its period (P) and semimajor axis (a) are taken from both the *Sixth Catalog of Orbits of Visual Binary Stars*[4] (Hartkopf et al. 2001) and the *Catalogue of Orbits and Ephemerides of Visual Double Stars* (Docobo et al. 2001). We also take orbital elements of the spectroscopic orbit (P_{12}, k_1, and e_{12}) from the *Ninth Catalog of Spectroscopic Binary Orbits* (Pourbaix et al. 2004).

Second, we have to estimate the most appropriate range for the M_1 and ΔM values, as well as to fix their respective step sizes. In the case of an SB1, according to Jaschek's criterion (Jaschek & Jaschek 1987), only stars that differ by less than about 1 mag are observable as a composite spectrum. Therefore, we can assume that $\Delta M = M_2 - M_1 \geq 1$.

Thus, the expression

$$\log \pi = \frac{M_1 - m_{12} - 5}{5} - \frac{1}{2}\log\left(1 + 10^{-0.4\Delta M}\right) \qquad (1)$$

provides the parallax values depending on M_1 and ΔM. Now we have to choose the set that is compatible with the margin of error given by *Hipparcos* ($\sigma_{\rm Hip}$). If there were no compatible values, then we should have to expand this interval up to a few $\sigma_{\rm Hip}$. This fact may indicate that the true parallax differs from that given by *Hipparcos*.

Lastly, for the mean values of M_1 and π, we calculate the corresponding values of M_2 (obtained from ΔM) and M_3 (inferred from m_3 and π).

In addition, new apparent visual magnitudes are also given. From now on, we will work with mean values of the three absolute magnitudes, three apparent magnitudes, and parallax (π_i).

2.3. *Computation of Masses and Spectral Types*

In the next step we calculate the mass and estimate the spectral type of each component. In order to obtain spectral types from absolute magnitudes, we use the calibration of Schmidt-Kaler (1982). We give spectral types with a mean error of two to three subclasses.

On the other hand, individual masses are calculated from a fit of data collected from the *Stellar Mass Catalogue* (Belikov 1995) (including giants, subgiants, and main-sequence stars) reached after a certain statistical procedure. Therefore, it will only be suitable for the restricted range of spectral types shown in Table 1.

These equations give relations between mass and spectral type for components of a binary system, where a and b are two coefficients that take several values depending on luminosity class. On the other hand, s is a continuous analytical variable defined by de Jager & Nieuwenhuijzen (1987) that represents the spectral class.

Since the mass function of the spectroscopic binaries is

$$\frac{(\mathcal{M}_2 \sin i_{12})^3}{(\mathcal{M}_1 + \mathcal{M}_2)^2} = 3.985 \times 10^{-20} k_1^3 P_{12}(1 - e_{12}^2)^{3/2},$$

where i_{12} is the inclination, k_1 is the radial velocity amplitude, P_{12} is the period, and e_{12} is the eccentricity, we can estimate the minimum mass and later the spectral type of the second component.

2.4. *Computation of Unknown Orbital Elements*

Once we have calculated masses, the semimajor axis and inclination of the spectroscopic orbit can be computed. Semimajor axis and inclination can be added to the known orbital elements. Therefore, the angle of the node will be the only orbital element that remains unknown.

Theoretically, it would be possible to determine the direction of the motion on the spectroscopic orbit by studying the perturbations due to the third component. A secular increase of the argument of periastron would suggest retrograde motion, while its decrease would correspond to a direct motion.

At the end of this process we obtain a new value for the parallax (π_f), which is calculated by means of

$$\pi_f = aP^{-2/3}\left(\sum_{j=1}^{n} \mathcal{M}_j\right)^{-1/3},$$

where a and P are the semimajor axis and the period of the visual orbit, respectively, $\mathcal{M}_j$ is the j-component mass calculated at the end of the process, and n is 3 (triple system) or 4 (quadruple system). Both π_i and π_f will indicate the most probable range for the parallax.

3. EXAMPLE: APPLICATION TO Hu 506 AB (WDS 00243+5201)

This triple system includes the bright star HD 1976, a single-lined spectroscopic binary with a period of 25.44 ± 0.03 days, whose orbit has been calculated by Abt et al. (1990). Their data are given in Table 2.

Only the observable spectrum has been cataloged as B5 IV by Lesh (1968). The current orbit elements of the visual double

TABLE 2

Orbital Elements for WDS 00243+5201: Visual Binary and Spectroscopic Subsystem

Hu 506 AB		HD 1976	
Parameter	Value[a]	Parameter	Value[b]
P (yr)...........	169.3 ± 3.0	P_{12} (days)....................	25.44 ± 0.03
T.................	1955.06 ± 0.50	T_0 (HJD).....................	2443840.3 ± 0.3
e..................	0.163 ± 0.008	k_1 (km s^{-1})................	23.4 ± 1.9
a (arcsec).....	0.214 ± 0.003	γ_0 (km s^{-1})................	-15.8 ± 1.3
i (deg)..........	64.8 ± 0.8	e_{12}..............................	0.14 ± 0.09
ω (deg)........	311.8 ± 1.0	ω_1 (deg).......................	165 ± 5
Ω (deg)........	30.1 ± 0.6	$a_{12} \sin i_{12}$ (10^6 km).....	8.10

[a] Docobo & Andrade (2005).

[b] Abt et al. (1990).

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[4] Available at http://ad.usno.navy.mil/wds/orb6/orb6.html.

ADS 328 (Hu 506), discovered by Hussey (1902), were calculated by Docobo & Andrade (2005) (see § 5), who obtained a period of 169.3 ± 3.0 yr and a semimajor axis of $0\farcs214 \pm 0\farcs003$ (its *Hipparcos* parallax is $\pi_{\rm Hip} = 2.38 \pm 0.69$ mas). The combined apparent magnitude of the Aa, Ab system and the B component are $m_{12} = 5.95$ and $m_3 = 6.84$, respectively.

Under these hypotheses, the expression (1) provides the parallax values depending on M_1 and ΔM. In this case we have obtained 66 compatible values, setting a step of 0.2 mag between 1.69 and 3.07 mas.

In the next step we estimate spectral type and mass of each component. Since mass function of the spectroscopic binary is $0.0328 \pm 0.0081\ \mathcal{M}_\odot$, the minimum mass and latest possible spectral type of the second component will be $1.1 \pm 0.3\ \mathcal{M}_\odot$ and F6 V, respectively.

Spectral types, obtained by using the calibration of Schmidt-Kaler (1982), are B4 IV, B9 IV, and B6 IV, respectively. Now, from first equation in Table 1 we calculate the masses: 5.6 ± 0.4, 3.4 ± 0.3, and $4.5 \pm 0.3\ \mathcal{M}_\odot$, respectively. Along with results for the triple systems, those for this star are given in Table 3.

With regard to the possibility of optically resolving this system, it can be noted that its angular separation never will be larger than 1.17 mas. In this way, Figure 1 shows the probable apparent orbit of the spectroscopic subcomponent.

4. METHODOLOGY APPLICATION RESULTS

In this section we give a detailed description and overview of the obtained results. We present the information on 61 triple systems, summarized in Table 3, where, as we said in § 2.1, the subscripts 1 and 2 refer to the spectroscopic subcomponents, and subscript 3 refers to the distant star. The Bu 1100 AB (WDS 01148+6056) system appears twice in Table 3 because there are two visual possible orbits. The results for nine quadruple systems are given in Table 4.

To test the methodology presented in this paper, we analyze the six spectroscopic binaries with visual or astrometric orbits to compare their known parameters with those obtained by us. Then, we also give a relation for the logarithm of the minimum semimajor axis as a function of the eccentricity. In addition, we make some comments about five W UMa–type eclipsing binaries and show their stellar radii in Table 5.

4.1. *Quadruple Systems with SB Subsystems*

We have analyzed nine quadruple systems comprising a pair of SBs. Eight of them are double 4(2, 2) systems and one is a hierarchical double 4(1, 3(2,1)) system. The results are listed in Table 4, while mobile diagrams for these systems are shown in Figure 2.

When we are dealing with multiple systems, we need to be more careful since the data from both subsystems are related. Therefore, the final results for each subsystem will also be related.

4.2. *Spectroscopic Binaries with Visual or Astrometric Orbit*

There are four SBs with calculated visual orbits and two SBs with composite orbits from astrometry. To compare our results with previous works, we analyze individually each of these cases.

1. *BAG 10 Aa* (*WDS 00568+6022*).—Bu 1099 is a quadruple system where the visual pair has one single-lined spectroscopic subsystem B. At the same time, the B component (BAG 10 Aa) comprises three stars: the close Ba, Bb spectroscopic pair and the $0\farcs0320$ distant component Bc. Its mobile diagram can be seen in Figure 2i.

TABLE 3

Summary of Derived Quantities for Triple Systems

WDS Name Grade[a] Quality[b]	$\mathcal{M}_1$ ($\mathcal{M}_\odot$) $\mathcal{M}_2$ ($\mathcal{M}_\odot$) $\mathcal{M}_3$ ($\mathcal{M}_\odot$)	Sp_1 Sp_2 Sp_3 SB[c]	m_1 m_2 a_{12} (mas) $\rho_{\max}$[d] (mas)	$\pi_{\rm Hip}$ (mas) π_i (mas) π_f (mas) i_{12}[e] (deg)
00063+5826	0.8 ± 0.1	K0 V	7.3 ± 0.2	49.30 ± 1.05
STF 3062 Ba, Bb, A	0.5 ± 0.1	M2 V	11.3 ± 0.3	49.7 ± 4.4
2	0.9 ± 0.1	G4 V	13.7 ± 1.7	49.6 ± 1.3
1		1	19.3 ± 2.5	6.4 ± 1.1
00243+5201	5.6 ± 0.4	B4 IV	6.1 ± 0.4	2.38 ± 0.69
Hu 506 Aa, Ab, B	3.4 ± 0.3	B9 IV	8.0 ± 0.6	2.3 ± 0.4
3	4.5 ± 0.3	B6 IV	1.03 ± 0.29	2.9 ± 0.2
5		1	1.17 ± 0.34	18.6 ± 4.1
00271−0753	0.9 ± 0.1	G6 V	8.9 ± 0.4	18.36 ± 2.75
A431 Ba, Bb, A	0.6 ± 0.1	K6 V	11.6 ± 0.5	18.5 ± 3.3
3	0.9 ± 0.1	G6 V	1.50 ± 0.42	19.5 ± 2.7
2		1	1.50 ± 0.42*	77 ± 63
00352−0336	1.0 ± 0.1	F9 V	5.8 ± 0.1	47.51 ± 1.15
Ho 212 Aa, Ab, B	0.8 ± 0.1	K0 V	7.4 ± 0.1	48.2 ± 2.5
1	0.9 ± 0.1	G6 V	1.87 ± 0.14	47.9 ± 1.0
1		1	1.87 ± 0.14*	30.3 ± 3.3
01148+6056(1)	0.9 ± 0.1	G3 V	9.6 ± 0.2	11.38 ± 1.66
Bu 1100 Aa, Ab, B	0.9 ± 0.1	G5 V	9.8 ± 0.2	11.3 ± 0.9
4	1.6 ± 0.1	F0 V	0.97 ± 0.12	13.4 ± 1.0
4		2	0.99 ± 0.12	66 ± 12
01148+6056(2)	0.9 ± 0.1	G3 V	9.6 ± 0.2	11.38 ± 1.66
Bu 1100 Aa, Ab, B	0.9 ± 0.1	G5 V	9.8 ± 0.2	11.3 ± 0.9
4	1.6 ± 0.1	F0 V	0.94 ± 0.12	12.9 ± 0.9
3		2	0.96 ± 0.12	71 ± 15
02039+4220	3.3 ± 0.1	B9 V	5.4 ± 0.3	9.19 ± 0.73
STT 38 Ba, Bb, C	2.4 ± 0.1	A3 V	6.7 ± 0.4	9.4 ± 1.1
2	2.6 ± 0.1	A2 V	0.63 ± 0.11	9.4 ± 0.2
1		2	0.81 ± 0.14	62 ± 10
04227+1503	1.1 ± 0.1	F8 V	7.4 ± 0.4	21.45 ± 2.76
STT 82 Aa, Ab, B	0.7 ± 0.1	K4 V	10.1 ± 0.5	21.6 ± 3.6
3	0.9 ± 0.1	G6 V	1.29 ± 0.31	21.8 ± 1.3
1		1	1.37 ± 0.33	35.2 ± 8.1
04290+1610	0.9 ± 0.1	G5 V	8.5 ± 1.0	20.58 ± 1.74
Hu 1080 Ba, Bb, A	0.6 ± 0.1	K5 V	10.6 ± 1.3	20.9 ± 9.3
2	1.4 ± 0.1	F2 V	4.0 ± 2.5	22.9 ± 0.6
3		1	5.0 ± 3.2	60 ± 46
04357+1010	2.3 ± 0.2	A6 IV	4.8 ± 0.1	21.68 ± 0.82
CHR 18 Aa, Ab, B	1.6 ± 0.2	F5 IV	5.8 ± 0.2	21.7 ± 1.3
3	1.4 ± 0.1	F2 V	1.44 ± 0.12	20.1 ± 0.5
2		1	1.44 ± 0.12*	67 ± 14
05117+0031	5.3 ± 0.2	B5 V	7.5 ± 0.3	2.03 ± 1.04
Hu 33 Aa, Ab, B	3.7 ± 0.1	B8 V	8.7 ± 0.4	1.8 ± 0.3
3	5.3 ± 0.2	B5 V	0.62 ± 0.14	1.8 ± 0.2
3		1	0.57 ± 0.13	73 ± 32
05364+2200	1.5 ± 0.1	F1 V	7.3 ± 0.2	15.35 ± 1.99
STF 742 Aa, Ab, B	0.9 ± 0.1	G4 V	9.0 ± 0.3	15.3 ± 1.7
5	1.4 ± 0.1	F2 V	6.1 ± 1.2	17.2 ± 2.6
3		1	6.6 ± 1.3	31.8 ± 6.4
06035+1941	8.8 ± 1.5	B7 III	6.2 ± 0.2	3.05 ± 0.96
McA 24 Aa, Ab, B	8.8 ± 1.5	B7 III	6.3 ± 0.3	2.9 ± 0.3
4	7.5 ± 1.4	B8 III	0.98 ± 0.17	3.2 ± 0.4
1		2	1.32 ± 0.23	15.8 ± 2.2

TABLE 3—*Continued*

WDS	$\mathcal{M}_1$ ($\mathcal{M}_\odot$)	Sp$_1$	m_1	$\pi_{\rm Hip}$ (mas)
Name	$\mathcal{M}_2$ ($\mathcal{M}_\odot$)	Sp$_2$	m_2	π_i (mas)
Grade[a]	$\mathcal{M}_3$ ($\mathcal{M}_\odot$)	Sp$_3$	a_{12} (mas)	π_f (mas)
Quality[b]		SB[c]	$\rho_{\rm max}$[d] (mas)	i_{12}[e] (deg)
07043−0303	0.8 ± 0.1	G7 V	8.9 ± 0.2	19.87 ± 1.93
A 519 Aa, Ab, B	0.6 ± 0.1	K6 V	11.1 ± 0.2	19.1 ± 1.6
4	0.8 ± 0.1	K0 V	1.37 ± 0.18	19.2 ± 1.2
1		1	1.37 ± 0.18*	28.4 ± 4.5
07277+2127	1.5 ± 0.1	F1 V	5.8 ± 0.1	29.38 ± 1.39
McA 30 Aa, Ab, B	1.2 ± 0.1	F6 V	6.3 ± 0.2	29.4 ± 1.9
2	0.9 ± 0.1	G2 V	1.24 ± 0.12	29.4 ± 1.0
1		2	1.27 ± 0.12	62.2 ± 6.9
08468+0625	2.0 ± 0.5	K1 III	3.7 ± 0.2	24.13 ± 1.29
†STF 1273 A, B, C	1.6 ± 0.2	F5 IV	5.6 ± 0.3	24.3 ± 2.1
4	1.4 ± 0.1	F2 V	255 ± 59	27.4 ± 2.2
3		1	320 ± 92	39 ± 12
08592+4803	1.7 ± 0.1	A9 V	3.4 ± 0.1	68.32 ± 0.79
HJ 2477 Aa, Ab, BC	1.1 ± 0.1	F7 V	4.6 ± 0.1	68.8 ± 2.3
5	0.6 ± 0.1	K8 V	484 ± 63	69 ± 10
1		1	629 ± 82	47.5 ± 8.7
09498+2111	3.1 ± 0.3	A0 IV	7.3 ± 0.3	6.34 ± 0.94
Kui 44 Aa, Ab, B	2.9 ± 0.3	A1 IV	7.4 ± 0.5	4.2 ± 0.7
3	4.4 ± 0.7	A3 III	0.379 ± 0.089	4.1 ± 0.1
5		1	0.379 ± 0.089*	62 ± 19
10373−4814	1.6 ± 0.2	F5 IV	4.6 ± 0.1	37.71 ± 0.51
SEE 119 Aa, Ab, B	1.5 ± 0.1	F1 V	5.3 ± 0.1	38.2 ± 1.6
3	1.2 ± 0.1	F6 V	4.85 ± 0.38	36.1 ± 2.0
1		2	7.31 ± 0.58	36.6 ± 2.8
11191+3811	2.4 ± 0.1	A3 V	5.3 ± 0.1	17.82 ± 0.75
55 UMa Aa, Ab, B	1.9 ± 0.1	A7 V	5.9 ± 0.2	17.9 ± 1.2
2	2.4 ± 0.1	A3 V	0.968 ± 0.095	16.3 ± 0.2
2		2	1.08 ± 0.11	42.7 ± 3.0
11308+4117	1.2 ± 0.1	F5 V	8.0 ± 0.2	12.77 ± 1.39
STT 234 Aa, Ab, B	1.1 ± 0.1	F8 V	8.5 ± 0.3	12.7 ± 1.2
2	1.2 ± 0.1	F6 V	1.26 ± 0.18	12.8 ± 0.6
1		2	1.38 ± 0.20	79 ± 30
12199−0040	3.4 ± 0.3	B9 IV	4.3 ± 0.2	13.06 ± 0.84
McA 37 Aa, Ab, B	2.7 ± 0.1	A1 V	5.1 ± 0.2	13.1 ± 1.1
2	2.4 ± 0.1	A3 V	7.36 ± 0.89	11.9 ± 0.3
2		2	9.2 ± 1.1	44.5 ± 3.9
13203+1746	1.8 ± 0.3	F6 V	8.0 ± 0.2	13.07 ± 0.87
‡A2166 Aa, Ab, B	0.2 ± 0.4	G5 V	9.5 ± 0.3	13.2 ± 1.2
2	1.1 ± 0.1	F8 V	0.222 ± 0.032	16.6 ± 1.3
5		2	0.222 ± 0.032*	31.0 ± 7.9
14131+5520	0.7 ± 0.1	K2 V	9.4 ± 0.1	26.43 ± 1.75
STF 1820 Aa, Ab, B	0.6 ± 0.1	K6 V	10.5 ± 0.1	26.3 ± 1.4
4	0.7 ± 0.1	K2 V	62 ± 11	27.7 ± 6.2
1		1	103 ± 18	53 ± 15
14404+2159	2.6 ± 0.1	A2 V	6.3 ± 0.2	9.47 ± 0.71
McA 40 A, B, C	1.6 ± 0.1	F0 V	7.8 ± 0.2	9.5 ± 0.8
2	2.1 ± 0.1	A5 V	6.23 ± 0.72	9.1 ± 0.2
1		1	6.79 ± 0.79	44.5 ± 5.3
14575−2125	0.5 ± 0.1	M1 V	8.3 ± 0.1	169.7 ± 1.0
†HN 28 B, C, A	0.4 ± 0.1	M5 V	11.1 ± 0.1	169.1 ± 5.5
5	0.7 ± 0.1	K4 V	143.9 ± 6.6	169.2 ± 5.8
1		2	196 ± 14	109 ± 18

TABLE 3—*Continued*

WDS	$\mathcal{M}_1$ ($\mathcal{M}_\odot$)	Sp$_1$	m_1	$\pi_{\rm Hip}$ (mas)
Name	$\mathcal{M}_2$ ($\mathcal{M}_\odot$)	Sp$_2$	m_2	π_i (mas)
Grade[a]	$\mathcal{M}_3$ ($\mathcal{M}_\odot$)	Sp$_3$	a_{12} (mas)	π_f (mas)
Quality[b]		SB[c]	$\rho_{\rm max}$[d] (mas)	i_{12}[e] (deg)
15038+4739	0.7 ± 0.1	K0 V	6.5 ± 0.1	78.39 ± 1.03
‡STF 1909 Ba, Bb, A	0.3 ± 0.1	K4 V	7.4 ± 0.1	79.3 ± 3.8
3	0.9 ± 0.1	G2 V	0.712 ± 0.061	87.1 ± 5.2
3		2	0.712 ± 0.061*	69 ± 13
15351−4110	12.1 ± 0.3	B1 V	3.5 ± 0.3	5.75 ± 1.24
HJ 4786 Aa, Ab, B	8.4 ± 0.2	B2 V	4.0 ± 0.4	5.6 ± 0.8
3	7.1 ± 0.2	B3 V	0.70 ± 0.14	6.6 ± 0.4
3		1	0.76 ± 0.15	8.2 ± 1.2
16147+3352	1.0 ± 0.1	G1 V	6.2 ± 0.1	46.11 ± 0.98
STF 2032 Aa, Ab, B	0.9 ± 0.1	G4 V	6.6 ± 0.1	45.9 ± 1.9
4	0.9 ± 0.1	G3 V	1.20 ± 0.10	45.6 ± 3.4
1		2	1.20 ± 0.10	31.1 ± 2.5
16555−0820	0.5 ± 0.1	M2 V	9.2 ± 0.1	174.22 ± 3.90
Kui 75 Ba, Bb, A	0.4 ± 0.1	M5 V	11.8 ± 0.1	144.9 ± 6.7
1	0.5 ± 0.1	M2 V	5.60 ± 0.44	147.3 ± 8.8
4		2	5.74 ± 0.45	14.5 ± 1.8
17053+5428	1.1 ± 0.1	F7 V	6.0 ± 0.1	37.08 ± 0.89
STF 2130 Ba, Bb, A	0.9 ± 0.1	G4 V	7.2 ± 0.1	36.3 ± 1.2
4	1.2 ± 0.1	F5 V	148 ± 11	34.7 ± 2.6
2		1	211 ± 16	16.9 ± 1.8
17217+3958	2.3 ± 0.1	A4 V	5.9 ± 0.2	15.53 ± 1.16
McA 47 Aa, Ab, B	1.6 ± 0.1	F0 V	7.0 ± 0.3	13.8 ± 1.6
2	2.6 ± 0.1	A2 V	0.71 ± 0.12	13.6 ± 0.4
3		1	0.71 ± 0.12*	64 ± 15
17394−1546	1.1 ± 0.1	F7 V	10.2 ± 0.6	6.21 ± 3.38
Hu 181 Ba, Bb, A	0.8 ± 0.1	G9 V	12.1 ± 0.8	5.3 ± 1.4
5	1.5 ± 0.1	F1 V	1.07 ± 0.43	12.1 ± 1.8
5		1	1.07 ± 0.43*	23.9 ± 7.8
17542+1108	2.6 ± 0.1	F1 V	7.4 ± 0.1	14.72 ± 0.81
‡FIN 381 Aa, Ab, B	0.5 ± 0.2	F8 V	8.2 ± 0.1	14.2 ± 0.5
2	1.3 ± 0.1	G3 IV	0.306 ± 0.016	12.4 ± 0.3
4		2	0.306 ± 0.016*	77 ± 18
17584+0428	0.6 ± 0.1	K9 V	11.6 ± 0.2	24.32 ± 2.28
Kui 84 Ba, Bb, A	0.5 ± 0.1	M1 V	12.2 ± 0.3	24.2 ± 2.3
4	0.7 ± 0.1	K5 V	5.08 ± 0.73	24.1 ± 1.5
1		2	6.24 ± 0.90	64 ± 14
18058+2127	0.9 ± 0.1	G2 V	7.5 ± 0.1	26.51 ± 1.35
STT 341 Aa, Ab, B	0.7 ± 0.1	K4 V	9.8 ± 0.1	26.1 ± 1.4
2	0.8 ± 0.1	K0 V	0.539 ± 0.041	25.6 ± 0.8
1		1	0.544 ± 0.043	63 ± 13
18208+7120	3.4 ± 0.3	B9 IV	4.5 ± 0.2	11.28 ± 0.48
STT 353 Aa, Ab, B	1.4 ± 0.2	F8 IV	7.4 ± 0.3	11.6 ± 1.2
3	2.7 ± 0.2	A3 IV	3.20 ± 0.49	10.8 ± 0.4
1		1	4.43 ± 0.68	47.3 ± 9.1
18537−0533	0.9 ± 0.1	G2 V	9.2 ± 0.5	12.59 ± 2.21
A 93 Aa, Ab, B	0.6 ± 0.1	K9 V	13.1 ± 0.6	12.7 ± 2.6
5	0.8 ± 0.1	G9 V	3.6 ± 1.2	11.8 ± 1.8
2		1	5.1 ± 1.7	51 ± 19
19062+3026	1.0 ± 0.1	G1 V	8.9 ± 0.2	13.26 ± 1.34
STF 2454 Aa, Ab, B	0.9 ± 0.1	G4 V	9.4 ± 0.3	13.3 ± 1.2
5	0.8 ± 0.1	G7 V	2.64 ± 0.47	12.1 ± 1.8
2		2	2.92 ± 0.52	59 ± 11

TABLE 3—*Continued*

WDS Name Grade[a] Quality[b]	$\mathcal{M}_1$ ($\mathcal{M}_\odot$) $\mathcal{M}_2$ ($\mathcal{M}_\odot$) $\mathcal{M}_3$ ($\mathcal{M}_\odot$)	Sp_1 Sp_2 Sp_3 SB[c]	m_1 m_2 a_{12} (mas) $\rho_{\max}$[d] (mas)	$\pi_{\rm Hip}$ (mas) π_i (mas) π_f (mas) i_{12}[e] (deg)
19111+3847	0.8 ± 0.1	G8 V	9.0 ± 0.1	20.52 ± 1.25
SE 2 Ca, Cb, B	0.8 ± 0.1	G9 V	9.1 ± 0.2	19.8 ± 1.5
2	0.9 ± 0.1	G3 V	25.5 ± 2.8	17.1 ± 0.6
4		1	30.0 ± 3.7	87 ± 57
19155−2515	3.1 ± 0.6	A9 III	6.4 ± 0.1	9.89 ± 1.12
B430 Ba, Bb, A	2.4 ± 0.1	A3 V	6.6 ± 0.2	9.7 ± 0.7
2	2.0 ± 0.6	K2 III	1.55 ± 0.17	9.2 ± 0.4
2		2	2.28 ± 0.25	63 ± 11
19351+5038	1.0 ± 0.1	F9 V	9.3 ± 0.2	9.89 ± 0.93
Hu 679 Aa, Ab, B	0.9 ± 0.1	G4 V	10.0 ± 0.3	10.0 ± 1.0
3	0.9 ± 0.1	G2 V	2.85 ± 0.44	10.1 ± 0.7
1		1	4.24 ± 0.65	29.6 ± 4.5
19411+1349	7.1 ± 0.2	B3 V	7.2 ± 0.4	1.98 ± 0.82
Kui 93 Aa, Ab, B	5.3 ± 0.2	B5 V	7.7 ± 0.5	1.8 ± 0.3
3	7.1 ± 0.2	B3 V	0.256 ± 0.070	3.1 ± 0.2
5		1	0.267 ± 0.073	10.3 ± 2.0
19550+4152	0.9 ± 0.1	G5 V	8.3 ± 0.1	22.31 ± 0.78
Ho 581 Aa, Ab, B	0.7 ± 0.1	K2 V	9.6 ± 0.1	22.5 ± 1.1
1	0.8 ± 0.1	G8 V	15.3 ± 1.0	23.1 ± 0.5
1		1	19.2 ± 1.6	7.2 ± 0.7
20216+1930	1.7 ± 0.1	A9 V	9.6 ± 0.3	4.55 ± 1.96
Cou 327 Aa, Ab, B	1.5 ± 0.1	F1 V	10.3 ± 0.4	4.1 ± 0.6
4	1.9 ± 0.1	A7 V	2.48 ± 0.51	5.0 ± 0.4
2		1	3.63 ± 0.82	31.6 ± 5.6
20374+7536	0.8 ± 0.1	K0 V	8.0 ± 0.1	36.16 ± 0.97
[‡]Hei 7 Aa, Ab, B	0.3 ± 0.1	K4 V	9.1 ± 0.2	36.8 ± 2.5
5	0.6 ± 0.1	K8 V	0.355 ± 0.050	41.7 ± 4.5
4		2	0.355 ± 0.050*	54 ± 11
20396+0458	0.6 ± 0.1	K5 V	8.9 ± 0.1	53.82 ± 2.21
Kui 99 Aa, Ab, B	0.6 ± 0.1	K6 V	9.3 ± 0.1	53.7 ± 2.9
3	0.6 ± 0.1	K8 V	121 ± 10	60.3 ± 2.8
3		2	208 ± 17	14.0 ± 1.2
20591+0418	1.8 ± 0.2	F2 IV	6.3 ± 0.2	16.59 ± 3.40
STF 2737 Aa, Ab, B	1.5 ± 0.1	F1 V	7.4 ± 0.3	16.3 ± 1.7
2	1.8 ± 0.2	F2 IV	0.81 ± 0.12	17.3 ± 0.5
1		1	0.94 ± 0.16	7.3 ± 0.9
21000+4004	0.5 ± 0.1	M2 V	10.9 ± 0.1	66.21 ± 2.54
Kui 103 Aa, Ab, B	0.4 ± 0.1	M4 V	11.8 ± 0.1	66.6 ± 2.7
4	0.4 ± 0.1	M4 V	2.35 ± 0.20	57.2 ± 4.8
3		2	2.45 ± 0.21	50.8 ± 9.5
21186+1134	1.0 ± 0.1	G1 V	8.1 ± 0.1	19.79 ± 1.18
Bu 163 Aa, Ab, B	0.9 ± 0.1	G2 V	8.2 ± 0.1	19.7 ± 1.0
2	0.8 ± 0.1	G7 V	1.231 ± 0.087	20.2 ± 0.5
1		2	1.231 ± 0.087	53.0 ± 4.6
21198−2621	0.8 ± 0.1	K0 V	7.3 ± 0.1	53.40 ± 1.09
Bu 271 Aa, Ab, B	0.8 ± 0.1	K1 V	7.8 ± 0.1	53.4 ± 2.2
5	0.6 ± 0.1	K8 V	10.0 ± 1.3	57.2 ± 8.6
2		1	10.9 ± 1.5	29.9 ± 5.0
21214+1020	2.7 ± 0.1	A1 V	7.7 ± 0.3	4.63 ± 0.92
A 617 Aa, Ab, B	1.6 ± 0.1	F0 V	9.6 ± 0.5	4.6 ± 0.7
1	2.9 ± 0.1	A0 V	0.83 ± 0.18	15.1 ± 0.2
5		1	0.88 ± 0.19	13.7 ± 2.2
21287+7034	18.5 ± 3.4	B3 III	3.2 ± 0.2	5.48 ± 0.47
LAB 6 Aa, Ab, Ac	2.2 ± 0.2	A7 V	8.1 ± 0.3	5.5 ± 0.6
3	3.1 ± 0.3	A0 V	0.94 ± 0.15	3.6 ± 0.3
5		1	1.43 ± 0.23	8.3 ± 1.8
21424+4105	2.3 ± 0.1	A4 V	7.0 ± 0.1	8.76 ± 0.61
Kui 108 Aa, Ab, B	2.1 ± 0.1	A5 V	7.2 ± 0.1	8.8 ± 0.5
2	2.4 ± 0.1	A3 V	0.420 ± 0.034	9.1 ± 0.2
1		2	0.420 ± 0.034*	46.7 ± 2.9
21446+2539	1.6 ± 0.2	F5 IV	5.2 ± 0.1	28.34 ± 0.88
Bu 989 Ba, Bb, A	1.0 ± 0.1	G0 V	7.2 ± 0.2	28.4 ± 2.0
1	1.9 ± 0.2	F0 IV	2.47 ± 0.25	28.0 ± 0.6
1		1	2.47 ± 0.25*	44.1 ± 6.3
22361+7253	1.1 ± 0.1	F7 V	8.5 ± 0.2	11.91 ± 0.67
Bu 1092 Aa, Ab, B	0.8 ± 0.1	G9 V	10.4 ± 0.2	12.0 ± 1.0
3	1.2 ± 0.1	F6 V	0.803 ± 0.095	12.0 ± 0.5
1		1	0.825 ± 0.098	42.6 ± 6.3
22535−1137	3.7 ± 0.1	B8 V	6.5 ± 0.1	4.96 ± 0.84
McA 73 Aa, Ab, B	3.3 ± 0.1	B9 V	6.6 ± 0.2	4.9 ± 0.4
3	3.7 ± 0.1	B8 V	0.438 ± 0.045	5.2 ± 0.1
1		2	0.439 ± 0.045	46.7 ± 3.3
22537+4445	1.8 ± 0.2	F2 IV	6.0 ± 0.2	19.22 ± 0.68
Bu 382 Aa, Ab, B	0.7 ± 0.1	K2 V	9.9 ± 0.2	19.1 ± 1.5
2	1.0 ± 0.1	F9 V	3.94 ± 0.43	17.7 ± 0.5
2		1	4.67 ± 0.64	12.2 ± 1.7
22570+2441	0.9 ± 0.1	G5 V	9.8 ± 0.2	11.55 ± 1.28
Cou 542 Aa, Ab, B	0.8 ± 0.1	G9 V	10.3 ± 0.3	11.6 ± 1.1
2	0.9 ± 0.1	G6 V	7.5 ± 1.0	13.4 ± 0.3
4		1	8.8 ± 1.2	33.9 ± 4.8
23079+7523	2.2 ± 0.5	G0 III	5.2 ± 0.1	14.83 ± 0.62
[†]STT 489 Aa, Ab, B	2.4 ± 0.1	A3 V	5.6 ± 0.1	14.9 ± 0.8
3	1.6 ± 0.1	F0 V	34.2 ± 3.1	15.5 ± 0.9
1		1	44.2 ± 4.0	100 ± 45
23126+0241	0.9 ± 0.1	G2 V	8.9 ± 0.1	15.21 ± 0.95
A2298 Aa, Ab, B	0.8 ± 0.1	G7 V	9.5 ± 0.2	15.2 ± 0.9
2	1.0 ± 0.1	G0 V	8.36 ± 0.74	15.4 ± 0.5
1		1	11.0 ± 1.0	17.7 ± 1.9
23524+7533	0.7 ± 0.1	K3 V	6.8 ± 0.1	92.68 ± 0.55
Bu 996 Ba, Bb, A	0.6 ± 0.1	K9 V	8.8 ± 0.1	93.2 ± 3.0
5	0.4 ± 0.1	M4 V	6.61 ± 0.86	80 ± 12
3		2	6.61 ± 0.86*	64 ± 14

NOTES.—A dagger (†) indicates that this binary has both spectroscopic and visual orbits. These three binaries are shown in Fig. 3. On the other hand, a double dagger (‡) indicates that the spectroscopic binary is a W UMa–type binary.

[a] Grade of visual orbit according to Hartkopf et al. (2001).

[b] Quality of results according to the two-dimensional parameter defined in § 4.2.

[c] SB1 or SB2 type.

[d] Maximum angular separation (asterisk indicates spectroscopic circular orbit).

[e] Spectroscopic binary inclination (or 180° − i_{12}).

By considering new speckle measurements for the Bab, Bc subsystem, we have calculated a new visual orbit (Docobo & Andrade 2006) for this *speckle astrometric* binary (see § 5.2). In this way, we have obtained an orbital inclination of 47°.6 ± 3°.0 and a semimajor axis of 32.0 ± 1.0 mas. From this orbit and

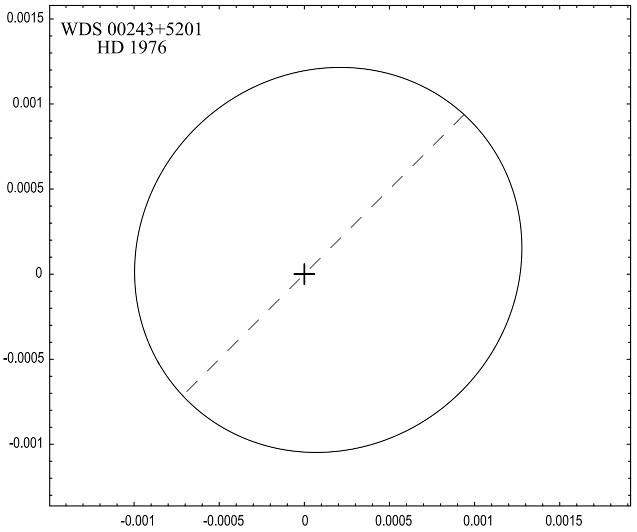

FIG. 1.—Probable apparent orbit of the spectroscopic subcomponent HD 1976 in Hu 506 AB (scale is in arcseconds).

taking into account the *Hipparcos* parallax, a total mass of 9.3 ± 3.2 $\mathcal{M}_\odot$ is obtained.

On the other hand, by applying the methodology that we explain in this paper, we have obtained the compatible values $i_{12} = 45\overset{\circ}{.}2 \pm 6\overset{\circ}{.}3$ and $a_{12} = 31.3 \pm 4.4$ mas. For spectral types and masses of the close pair we have obtained B9 V with 3.3 ± 0.1 $\mathcal{M}_\odot$ and A5 V with 2.1 ± 0.1 $\mathcal{M}_\odot$ for the Ba and Bb components, respectively. Moreover, the third component should be a B9 IV star with 3.4 ± 0.3 $\mathcal{M}_\odot$.

2. *Sp 1 AB* (*WDS 08468+0625*).—STF 1273 is a quintuple system comprising the close visual AB pair (our target system), the 3″ distant SB1 C, and a 19″ distant component D.

The AB pair was studied by Hartkopf et al. (1996), who, taking into account 12 speckle measurements obtained since 1989, computed very accurate orbital elements, grading with one by Hartkopf et al. (2001). They inferred a mean orbital inclination of $50\overset{\circ}{.}01 \pm 0\overset{\circ}{.}27$. The semimajor axis obtained for this orbit is 254.7 ± 0.9 mas. Recently, Parsons (2004) has determined, on the basis of isochrone fitting of multiple cool-plus-hot systems, the parameters $\log \sin i_{12} = -0.19$ and $a_{12} = 249$ mas. He also gives spectral types and masses for both components: G7 III with 2.2 $\mathcal{M}_\odot$ and A7 with 1.9 $\mathcal{M}_\odot$ for the A and B components, respectively.

Now, by applying our methodology, we have obtained the compatible values $i_{12} = 39^\circ \pm 12^\circ$ and $a_{12} = 255 \pm 59$ mas. For spectral types and masses of the close pair we have obtained K1 III with 2.0 ± 0.5 $\mathcal{M}_\odot$ and F5 IV with 1.6 ± 0.2 $\mathcal{M}_\odot$ for the A and B components, respectively. According to our results, the third component should be an F2 V star with 1.4 ± 0.1 $\mathcal{M}_\odot$.

3. *ξ UMa Aa* (*WDS 11182+3132*).—STF 1523 is also a quintuple system where the visual pair has two single-lined spectroscopic subsystems A and B. At the same time, the B component comprises three stars. Its mobile diagram can be seen in Figure 2vi.

In this case, there are two composite orbits of the spectroscopic pair Aa, Ab calculated from astrometric data, Mason et al. (1995) and Heintz (1996), from which $i_{12} = 94\overset{\circ}{.}9$, $a_{12} = 57$ mas and $i_{12} = 91^\circ$, $a_{12} = 54$ mas, respectively, are derived.

In contrast, we obtain $i_{12} = 35\overset{\circ}{.}0 \pm 4\overset{\circ}{.}6$ (or $i_{12} = 145\overset{\circ}{.}0 \pm 4\overset{\circ}{.}6$ if the motion is retrograde) and $a_{12} = 215 \pm 20$ mas. This strong disagreement between their parameters and our results could be explained by the fact that both orbits are not reliable; in fact, they are astrometric orbits and both subcomponents have never been observed separately.

Only the spectral types given by Mason et al. (1995) are consistent with those obtained by us: for the Aa component (G0 V and G3 V, respectively), Ab (M3 V?/K3 V), Ba (G5 V/G6 V), and Bc (K2–3 V/K5 V). No spectral type has been assigned to the Bb component yet.

4. *HN 28 BC* (*WDS 14575−2125*).—The HN 28 triple system comprises the close visual BC pair and a 32″ distant component A.

With the aim of calculating accurate masses for this system, Forveille et al. (1999) have determined the orbital elements $i_{12} = 107\overset{\circ}{.}6 \pm 0\overset{\circ}{.}7$ and $a_{12} = 150.7 \pm 0.7$ mas, and the masses (Delfosse et al. 2000) $\mathcal{M}_B = 0.5656 \pm 0.0029\ \mathcal{M}_\odot$ and $\mathcal{M}_C = 0.3770 \pm 0.0018\ \mathcal{M}_\odot$, with composite spectral type M1 V. At the same time, Pourbaix (2000) has calculated another orbit with $i_{12} = 110^\circ \pm 2\overset{\circ}{.}4$ and $a_{12} = 133. \pm 3.9$ mas. He also determined that $\mathcal{M}_B = 0.51 \pm 0.038\ \mathcal{M}_\odot$ and $\mathcal{M}_C = 0.37 \pm 0.023\ \mathcal{M}_\odot$.

We have found $i_{12} = 109^\circ \pm 18^\circ$ and $a_{12} = 143.9 \pm 6.6$ mas. The corresponding masses are $\mathcal{M}_B = 0.5 \pm 0.1\ \mathcal{M}_\odot$ and $\mathcal{M}_C = 0.4 \pm 0.1\ \mathcal{M}_\odot$, with spectral types M1 V and M5 V, respectively. In addition, for the A component we have obtained $\mathcal{M}_A = 0.7 \pm 0.1\ \mathcal{M}_\odot$ with K4 V.

5. *BAG 6 Aa* (*WDS 18002+8000*).—STF 2308 is a quadruple system that comprises two spectroscopic binaries: 40 Dra (B) and 41 Dra (A). The last one has been resolved by speckle interferometry, and it is also known as BAG 6 Aa. Its mobile diagram can be seen in Figure 2viii.

This subsystem has been studied by Tokovinin et al. (2003), who calculated a semimajor axis $a_{12} = 70.6 \pm 1.4$ mas and an orbital inclination $i_{12} = 49\overset{\circ}{.}7 \pm 2\overset{\circ}{.}9$. They also obtained masses for both components of BAG 6 Aa: $\mathcal{M}_{\rm Aa} = 1.28 \pm 0.15\ \mathcal{M}_\odot$ and $\mathcal{M}_{\rm Ab} = 1.20 \pm 0.14\ \mathcal{M}_\odot$. With regard to the spectral types they concluded that all components are slightly evolved F-type stars.

By applying the methodology shown in this paper, we have found $a_{12} = 76 \pm 13$ mas and $i_{12} = 35\overset{\circ}{.}9 \pm 4\overset{\circ}{.}4$. For the masses our results are $\mathcal{M}_{\rm Aa} = 1.7 \pm 0.1\ \mathcal{M}_\odot$ and $\mathcal{M}_{\rm Ab} = 1.5 \pm 0.1\ \mathcal{M}_\odot$. Spectral types are A9 V, F1 V, F1 V, and F5 V, for the Aa, Ab, Ba, and Bb components, respectively.

6. *π Cep Aa* (*WDS 23079+7523*).—STT 489 is a triple system comprising the spectroscopic subcomponents Aa, Ab and a $0\overset{\prime\prime}{.}27$ distant component B. Since the composite spectrum for the spectroscopic binary is G2 III, according to the decomposition procedure (Edwards 1976) we would expect that the individual spectra are G3 III and F3 V, respectively.

Recently, Gatewood et al. (2001) have carried out a study of astrometric data to determine orbital elements and masses from astrometry, where they take a parallax slightly lower than the *Hipparcos* one. They have found $i_{12} = 99\overset{\circ}{.}0 \pm 2\overset{\circ}{.}5$, $a_{12} = 34.8 \pm 1.24$ mas, and a total system mass of $8.81 \pm 0.87\ \mathcal{M}_\odot$ ($\mathcal{M}_A = 6.88 \pm 0.69\ \mathcal{M}_\odot$ and $\mathcal{M}_B = 1.93 \pm 0.23\ \mathcal{M}_\odot$). Taking into account the orbital parameters, they have found $\mathcal{M}_{\rm Aa} = 3.63 \pm 0.53\ \mathcal{M}_\odot$ and $\mathcal{M}_{\rm Ab} = 3.27 \pm 0.48\ \mathcal{M}_\odot$. As regards the spectral types, they have determined that the Aa component is a K0 III, leaving indeterminate the spectral type of the Ab component. In addition, they have classified the third component as A8 V.

We have obtained $i_{12} = 100^\circ \pm 45^\circ$ and $a_{12} = 34.2 \pm 3.1$ mas, in a very good agreement with the previous work. We have also determined the spectral types and the masses: G0 III and 2.2 ± 0.5 $\mathcal{M}_\odot$, A3 V and 2.4 ± 0.1 $\mathcal{M}_\odot$, and F0 V and 1.6 ± 0.1 $\mathcal{M}_\odot$ for the Aa, Ab, and B components, respectively. In spite of the excellent agreement between orbital elements and considering that the spectra are quite similar, the difference between both mass

TABLE 4

Summary of Derived Quantities for Quadruple Systems

WDS Name Grade^A Grade^B Quality^A Quality^B	$\mathcal{M}_1$ ($\mathcal{M}_\odot$) $\mathcal{M}_2$ ($\mathcal{M}_\odot$) $\mathcal{M}_3$ ($\mathcal{M}_\odot$) $\mathcal{M}_4$ ($\mathcal{M}_\odot$) SB^A SB^B	Sp$_1$ Sp$_2$ Sp$_3$ Sp$_4$ a_{12}^A (mas) a_{12}^B (mas)	m_1 m_2 m_3 m_4 $\rho_{\rm max}^A$ (mas) $\rho_{\rm max}^B$ (mas)	$\pi_{\rm Hip}$ (mas) π_i^A (mas) π_i^B (mas) π_f (mas) i_{12}^A (deg) i_{12}^B (deg)
00568+6022	3.4 ± 0.3	B9 IV	6.1 ± 0.5	5.31 ± 0.61
†Bu 1099 A, Ba, Bb, Bc	3.4 ± 0.3	B9 IV	5.9 ± 0.3	5.3 ± 0.5
2	2.9 ± 0.1	A0 V	6.9 ± 0.4	5.3 ± 0.7
. . .	3.7 ± 0.1	B8 V	6.3 ± 0.6	5.4 ± 0.1
4	1	31.3 ± 4.4	33.8 ± 4.9	45.2 ± 6.3
1	2	0.49 ± 0.09	0.55 ± 0.10	47.2 ± 7.3
03368+0035	1.1 ± 0.1	F8 V	6.3 ± 0.1	34.52 ± 0.87
STF 422 Aa, Ab, Ba, Bb	0.9 ± 0.1	G5 V	7.4 ± 0.2	35.2 ± 2.5
5	0.7 ± 0.1	K4 V	9.1 ± 0.1	34.8 ± 2.0
5	0.6 ± 0.1	K8 V	10.7 ± 0.2	32.9 ± 0.7
1	2	1.73 ± 0.18	1.73 ± 0.18*	38.2 ± 3.1
2	1	84 ± 48	116 ± 69	8.8 ± 5.1
06024+0939	2.7 ± 0.1	A1 V	4.4 ± 0.2	21.49 ± 0.82
A2715 Aa, Ab, Ba, Bb	1.2 ± 0.1	F5 V	6.8 ± 0.3	21.8 ± 1.9
2	1.2 ± 0.1	F5 V	6.8 ± 0.1	21.5 ± 1.2
2	1.1 ± 0.1	F7 V	7.2 ± 0.1	20.7 ± 0.2
1	1	1.80 ± 0.23	1.80 ± 0.23	27.9 ± 3.3
1	2	1.63 ± 0.13	1.63 ± 0.13*	69 ± 11
07346+3153	2.7 ± 0.1	A1 V	2.0 ± 0.2	63.27 ± 1.23
STF 1110 Aa, Ab, Ba, Bb	1.1 ± 0.1	F8 V	5.0 ± 0.2	64.4 ± 5.1
3	1.9 ± 0.1	A7 V	3.2 ± 0.1	63.3 ± 3.0
3	1.1 ± 0.1	F7 V	4.8 ± 0.1	59.7 ± 3.6
1	1	8.4 ± 1.0	12.2 ± 1.5	14.9 ± 1.8
1	1	3.65 ± 0.30	3.65 ± 0.30*	23.5 ± 2.3
08285−0231	1.6 ± 0.1	F0 V	7.3 ± 0.1	11.73 ± 0.94
A551 Aa, Ab, Ba, Bb	1.1 ± 0.1	F7 V	8.4 ± 0.1	11.8 ± 0.6
2	1.5 ± 0.1	F1 V	7.8 ± 0.1	11.7 ± 0.7
2	1.5 ± 0.1	F1 V	8.0 ± 0.1	11.0 ± 0.5
1	1	0.60 ± 0.05	0.60 ± 0.05	70 ± 14
1	2	1.09 ± 0.09	1.09 ± 0.09*	33.5 ± 2.4
11182+3132	0.9 ± 0.1	G3 V	4.5 ± 0.1	113.20 ± 4.60
†STF 1523 Aa, Ab, Ba, Bb	0.7 ± 0.1	K3 V	6.3 ± 0.2	114.0 ± 7.5
1	0.9 ± 0.1	G6 V	4.9 ± 0.2	115.9 ± 9.7
1	0.6 ± 0.1	K5 V	7.2 ± 0.2	113.6 ± 2.6
2	1	215 ± 20	305 ± 29	35.0 ± 4.6
2	1	6.93 ± 0.82	6.93 ± 0.82*	4.0 ± 0.5
13461+0507	1.1 ± 0.1	F8 V	8.2 ± 0.2	15.39 ± 2.72
‡STF 1781 Aa, Ab, Ba, Bb	0.8 ± 0.1	G7 V	9.5 ± 0.3	15.3 ± 1.5
3	1.1 ± 0.3	G1 V	8.7 ± 0.2	15.2 ± 1.7
3	1.0 ± 0.4	G4 V	9.1 ± 0.3	15.0 ± 1.0
2	1	4.11 ± 0.60	4.95 ± 0.73	14.4 ± 2.0
1	2	0.222 ± 0.037	0.222 ± 0.037*	76 ± 42
18002+8000	1.7 ± 0.1	A9 V	6.2 ± 0.2	18.84 ± 1.81[a]
†STF 2308 Aa, Ab, Ba, Bb	1.5 ± 0.1	F1 V	6.7 ± 0.2	19.1 ± 1.7
. . .	1.5 ± 0.1	F1 V	6.5 ± 0.3	19.5 ± 2.5
. . .	1.2 ± 0.1	F5 V	7.0 ± 0.4	21.6 ± 2.4
5	2	76 ± 13	133 ± 23	35.9 ± 4.4
4	2	3.08 ± 0.66	3.87 ± 0.83	27.8 ± 3.8

TABLE 4—*Continued*

WDS	$\mathcal{M}_1$ ($\mathcal{M}_\odot$)	Sp$_1$	m_1	$\pi_{\rm Hip}$ (mas)
Name	$\mathcal{M}_2$ ($\mathcal{M}_\odot$)	Sp$_2$	m_2	π_i^A (mas)
Grade^A	$\mathcal{M}_3$ ($\mathcal{M}_\odot$)	Sp$_3$	m_3	π_i^B (mas)
Grade^B	$\mathcal{M}_4$ ($\mathcal{M}_\odot$)	Sp$_4$	m_4	π_f (mas)
Quality^A	SB^A	a_{12}^A (mas)	$\rho_{\rm max}^A$ (mas)	i_{12}^A (deg)
Quality^B	SB^B	a_{12}^B (mas)	$\rho_{\rm max}^B$ (mas)	i_{12}^B (deg)
23304+3050	1.2 ± 0.1	F6 V	8.8 ± 0.2	9.68 ± 1.50
Bu 1266 Aa, Ab, Ba, Bb	1.0 ± 0.1	G0 V	9.6 ± 0.3	9.6 ± 0.9
2	1.2 ± 0.1	F6 V	8.6 ± 0.3	9.6 ± 1.2
2	1.0 ± 0.1	F9 V	9.2 ± 0.4	8.7 ± 0.2
1	2	0.360 ± 0.047	0.375 ± 0.049	37.7 ± 3.5
1	2	1.30 ± 0.23	1.68 ± 0.30	44.2 ± 5.5

Notes.—*A* and *B* superscripts indicate the two SBs of the global system. As in Table 3, "Grade" is the grade of visual orbit according to Hartkopf et al. (2001), "Quality" refers to the quality of results according to the two-dimensional parameter defined in § 4.2, "SB" refers to SB1 or SB2 type, "$\rho_{\rm max}$" refers to the maximum angular separation (an asterisk indicates spectroscopic circular orbit), and "i_{12}" indicates spectroscopic binary inclination (or $180^\circ - i_{12}$). A dagger (†) indicates that the Bab, Bc, A subsystem in Bu 1099 AB; the Aa, Ab, B subsystem in STF 1523 AB; and the Aa, Ab, B subsystem in STF 2308 AB also have visual orbits. These three binaries are shown in Fig. 3. A double dagger (‡) indicates that the Ba, Bb, A subsystem in STF 1781 AB is a W UMa–type SB.

[a] The Ba, Bb subcomponent has $\pi_{\rm Hip} = 19.64 \pm 3.80$ mas.

assignments can only be explained by the use of different mass-luminosity calibrations.

In summary, considering the above-mentioned comments we can conclude that for BAG 10 Aa and Sp 1 AB our derived quantities are completely compatible with the Docobo & Andrade (2006) and Hartkopf et al. (1996) orbits, respectively. For HN 28 BC we have two previous reliable orbits that are also compatible with ours. The same is valid for π Cep Aa and BAG 6 Aa.

On the other hand, ξ UMa Aa is the only one that disagrees with the previous orbits (both graded 9 and without assigned errors), independently of whether or not the motion is direct (3dir or 3ret, respectively, in Fig. 3). Even the semimajor axis is very different. More investigation is necessary to know the source of this disagreement.

From our analysis and considering the goodness of the previous orbits, we can say that in the five cases out of six (where there are previous definitive, or at least reliable, orbits) the agreement is very good (see Fig. 3).

With the aim of calibrating the quality of our results, we have defined a two-dimensional parameter that measures how much the initial and final parallaxes described in this paper differ from the *Hipparcos* parallax:

$$\Pi = \left(\frac{\pi_f}{\pi_{\rm Hip}}, \frac{\pi_i}{\pi_{\rm Hip}}\right).$$

In Figure 4 we see SB systems distributed in the Π-plane (there are three outliers with $\pi_f/\pi_{\rm Hip} > 1.5$). We have classified the systems in five quality grading boxes according to the distance to the (1, 1)-point. This allows us to grade the results in this way:

1. *Very good*.—Box$_1 \equiv \{(0.95, 0.95) < \Pi_{\rm system} < (1.05, 1.05)\}$.
2. *Good*.—Box$_2 \equiv \{(0.90, 0.90) < \Pi_{\rm system} < (1.10, 1.10)\} -$ Box$_1$.
3. *Reliable*.—Box$_3 \equiv \{(0.85, 0.85) < \Pi_{\rm system} < (1.15, 1.15)\} -$ Box$_2$.
4. *Preliminary*.—Box$_4 \equiv \{(0.80, 0.80) < \Pi_{\rm system} < (1.20, 1.20)\} -$ Box$_3$.
5. *Indeterminate*.—Box$_5 \equiv \{\Pi_{\rm system} > (1.20, 1.20)\}$.

With this criterion we have found (see Fig. 5) that almost half of the systems (47%) are in the first category and only seven systems (8.9%) are in the last category.

4.3. *Relation between the Logarithm of Minimum Semimajor Axis and the Eccentricity*

It is well known that close binaries undergo tidal dissipation, which implies orbital circularization. With the aim of confirming whether our data verified this phenomena, we plotted the logarithm of the semimajor axis versus the eccentricity of the spectroscopic orbit for 73 SB1s and SB2s (all those investigated in this paper, excluding the five W UMa–type SBs and one outlier). In this way, we have found the following empirical relation among them (valid for non–W UMa type SBs):

$$\log a_{12} = -1.75 + 0.85e_{12} + 1.55e_{12}^2. \tag{2}$$

In Figure 6 we compare this relation with those obtained by using the data given by Pourbaix (2000) for 40 SB2s with known semimajor axes in AU and eccentricities ($\log a_{12} = -1.2 + 0.45e_{12} + 0.75e_{12}^2$). We think that the coefficients of expression (2) are more accurate because our data set is bigger than Pourbaix's.

In any case, it appears clear that there is a trend toward circularization. Therefore, expression (2) suggests that for a given eccentricity there is a minimum semimajor axis and that it decreases as the eccentricity decreases. Thus, the smaller the semimajor axis, the more circular the orbit becomes.

TABLE 5

Derived Radii for W UMa–Type Subsystems

WDS	Name	W UMa Type	$\mathcal{R}_1$ ($\mathcal{R}_\odot$)	$\mathcal{R}_2$ ($\mathcal{R}_\odot$)
13203+1746	V* KR Com	A	1.8 ± 0.2	0.7 ± 0.5
13461+0507	V* HT Vir	A[a]	1.1 ± 0.2	1.0 ± 0.2
15038+4739	V* i Boo	W	0.8 ± 0.0	0.6 ± 0.1
17542+1108	V* V2388 Oph	A	2.2 ± 0.1	1.0 ± 0.1
20374+7536	V* VW Cep	W	0.9 ± 0.1	0.6 ± 0.1

[a] In spite of being an A-type eclipsing binary, it appears that a W-type mass-luminosity relation matches better the mass ratio.

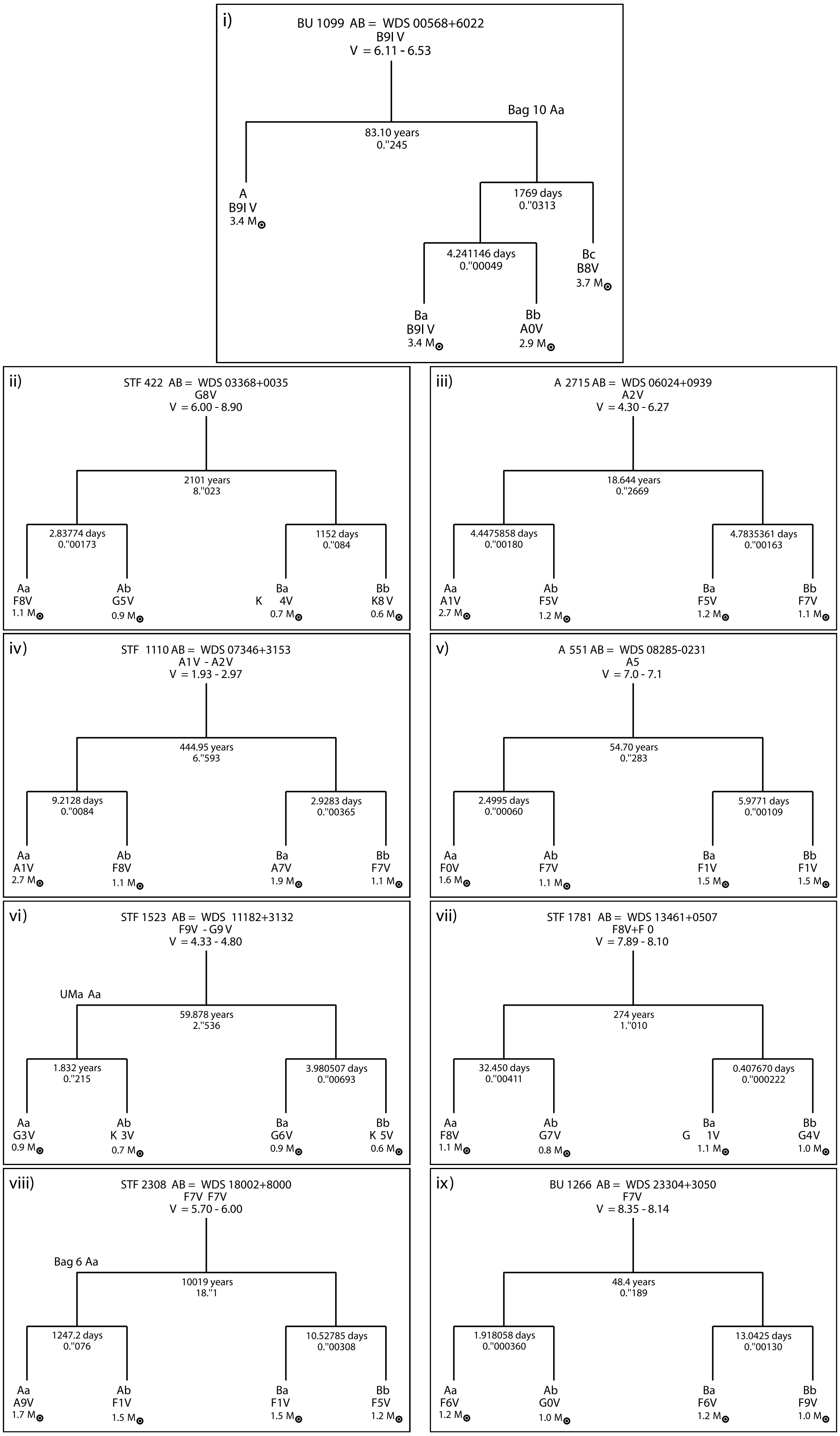

FIG. 2.—Mobile diagrams of quadruple systems: (i) Bu 1099 AB, (ii) STF 422 AB, (iii) A2715 AB, (iv) STF 1110 AB, (v) A551 AB, (vi) STF 1523 AB, (vii) STF 1781 AB, (viii) STF 2308 AB, and (ix) Bu 1266 AB.

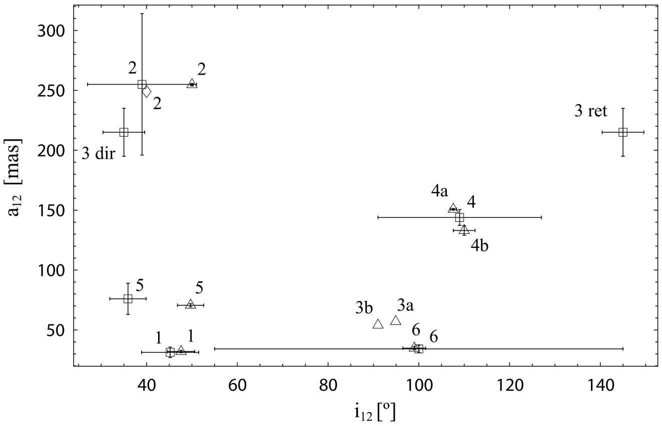

FIG. 3.—Distribution of the six visual-spectroscopic binaries in the i_{12}-a_{12} plane. Our results are indicated by a numbered square (according to numeration used in § 4.2), while those of previous works are indicated by the corresponding numbered triangle: 1 (Docobo & Andrade 2006), 2 (Hartkopf et al. 1996), 3a (Mason et al. 1995), 3b (Heintz 1996), 4a (Forveille et al. 1999), 4b (Pourbaix 2000), 5 (Tokovinin et al. 2003), and 6 (Gatewood et al. 2001). A diamond is used for the values given by Parsons (2004) (see § 4.2).

4.4. *W UMa–Type Spectroscopic Binaries*

In the course of our study we have analyzed five eclipsing binaries of W UMa type: V* KR Com (WDS 13203+1746), V* HT Vir (WDS 13461+0507), V* i Boo (WDS 15038+4739), V* V2388 Oph (WDS 17542+1108), and V* VW Cep (WDS 20374+7536).

To apply our methodology, we had to take into account the fact that W UMa–type star systems are contact binaries (Lucy 1968a, 1968b) of spectral types F, G, or K in almost all cases. Both components are embedded in a common convective envelope, and their luminosities are nearly equal. A lot of them are double-lined binaries with the smallest mass ratios (q) known among contact binaries ($q < 0.5$, sometimes $q < 0.1$), much lower than we can expect for the luminosity ratio. Because of this we had to make a suitable mass-luminosity calibration for these kinds of stars. In this study we have used the mass-luminosity and mass-radius relations for both W and A subtypes of the W UMa–type binaries given by Awadalla & Hanna (2005). The radii derived for these systems according to these relations are listed in Table 5.

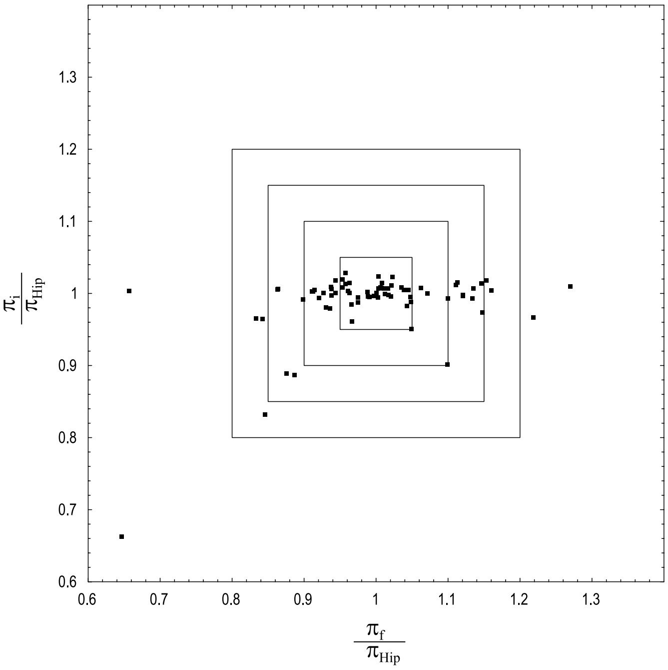

FIG. 4.—Quality grading boxes.

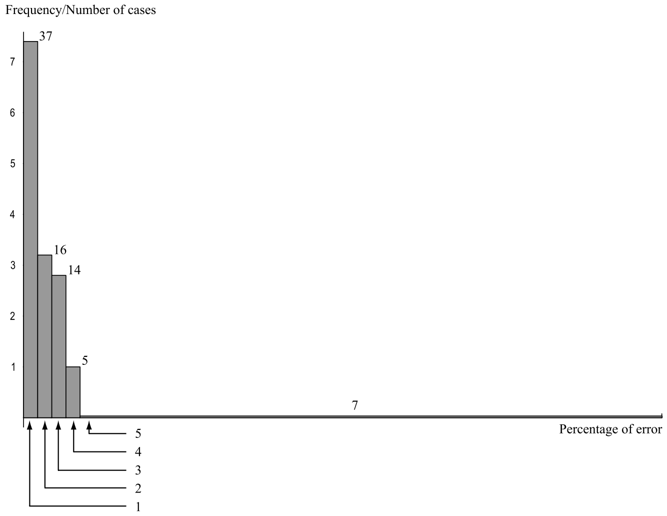

FIG. 5.—Quality grading histogram.

5. NEW ORBITS OF VISUAL BINARIES

By considering all the available micrometric and speckle measurements and by using the analytical method of Docobo (1985), we have computed the orbits of Hu 506 AB (WDS 00243+5201), BAG 10 Aa (WDS 00568+6022), and LAB 6 Aa (WDS 21287+7034). Hu 506, BAG 10 Aa, and LAB 6 Aa have been announced previously in the IAU Commission 26 Information

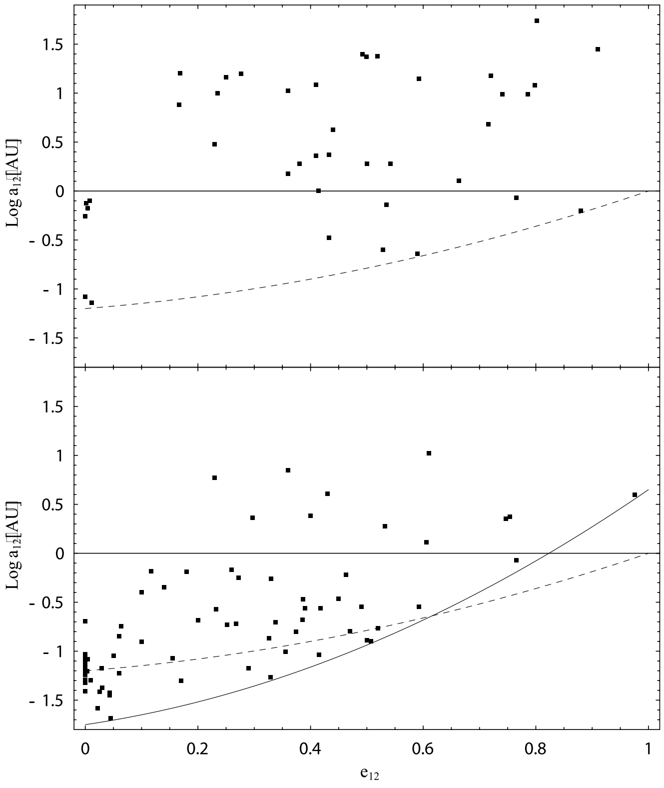

FIG. 6.—Relation among logarithm of minimum semimajor axis and eccentricity for the SB2 data of Pourbaix (2000) (*top*) is shown as a dashed line, while that obtained from present work (*bottom*) is shown as a solid line.

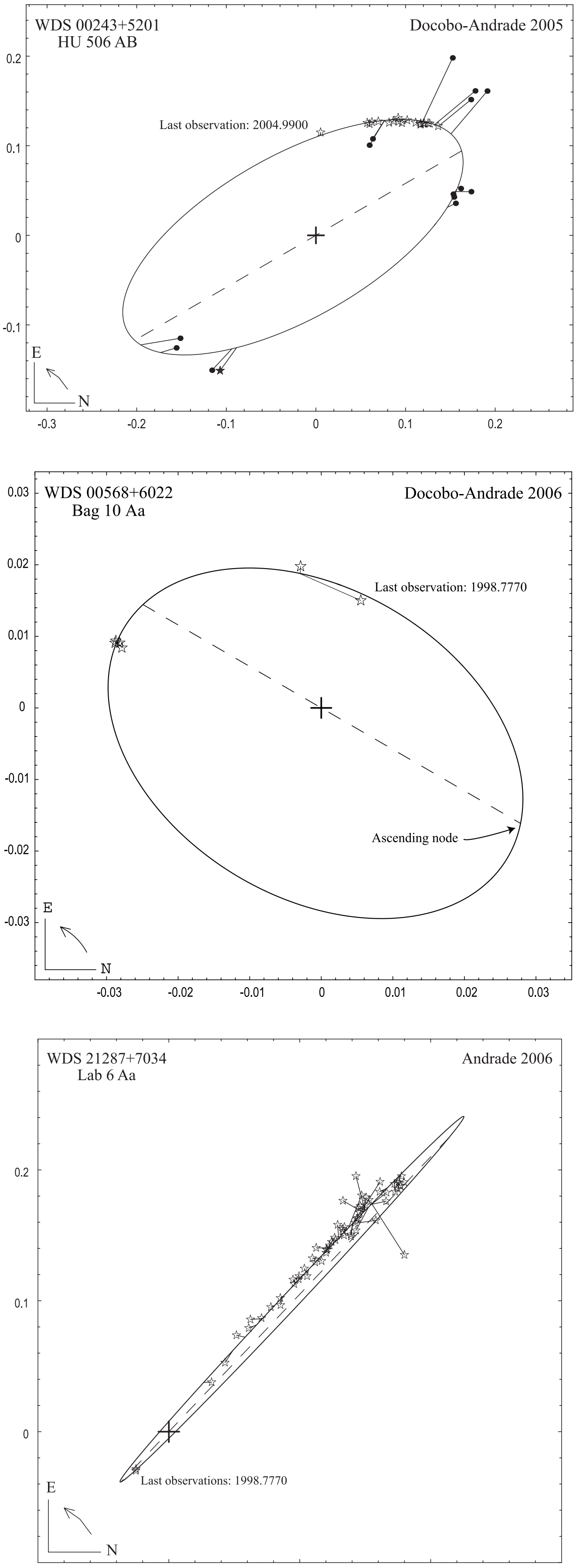

Fig. 7.—New orbits for the visual binaries Hu 506 AB, BAG 10 Aa, and LAB 6 Aa (scale is in arcseconds).

TABLE 6

Measurements and $O - C$ Differences for the Hu 506 AB Orbit

Epoch	θ (deg)	ρ (arcsec)	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)	Number of Nights	Observers[a]
1902.710...........	217.2	0.190	5.2	−0.041	3	Hu
1908.870...........	218.9	0.200	1.9	−0.017	2	A
1923.110...........	232.4	0.190	−1.1	0.032	1	A
1923.874...........	234.7	0.185	−0.0	0.032	3	Mag
1958.660...........	12.9	0.160	0.9	0.010	2	B
1960.080...........	15.5	0.160	1.0	0.004	6	VBs
1961.860...........	15.7	0.180	−1.7	0.016	2	Cou
1962.314...........	16.7	0.160	−1.3	−0.005	4	B
1962.809...........	17.9	0.170	−0.9	0.003	3	Wor
1977.660...........	40.1	0.250	3.2	0.062	3	Hei
1981.690...........	41.2	0.230	−0.5	0.047	3	Hei
1982.681...........	41.8	0.183	−1.1	0.002	. . .	Fu
1982.770...........	42.2	0.240	−0.8	0.059	2	Cou
1983.710...........	45.0	0.177	0.8	−0.002	1	McA
1984.055...........	44.5	0.178	−0.1	−0.000	1	McA
1984.702...........	46.0	0.174	0.5	−0.003	1	McA
1984.999...........	46.1	0.173	0.2	−0.003	1	McA
1985.750...........	52.4	0.250	5.5	0.076	2	Hei
1985.840...........	46.8	0.171	−0.2	−0.003	1	McA
1985.845...........	46.7	0.170	−0.3	−0.004	1	McA
1986.886...........	48.5	0.168	0.0	−0.003	1	McA
1988.655...........	51.6	0.164	0.6	−0.002	1	Mca
1988.909...........	52.6	0.158	1.3	−0.007	. . .	Fu
1991.250...........	54.0	0.157	−1.0	−0.000	1	HIP
1991.902...........	55.9	0.154	−0.2	−0.002	1	Hrt
1992.688...........	55.0	0.160	−2.5	0.007	1	Miu
1992.694...........	57.0	0.150	−0.5	−0.003	1	Miu
1993.660...........	59.5	0.125	0.3	−0.024	1	Doc
1993.660...........	59.3	0.117	0.1	−0.032	1	Lin
1994.708...........	61.3	0.145	0.1	−0.000	1	Hrt
1995.768...........	63.7	0.141	0.4	−0.000	1	Hrt
1996.538...........	64.3	0.138	−0.6	−0.001	1	Hrt
1996.866...........	65.5	0.138	−0.0	0.000	1	Hrt
2004.990...........	87.4	0.115	0.0	0.003	1	Doc

[a] Code for the original reference. Code format is the WDS Discoverer Designation code (usually the first three letters of the first author's name).

Circulars 156 (Docobo & Andrade 2005), 159 (Docobo & Andrade 2006), and 158 (Andrade 2006), respectively.

Micrometric data are indicated in Figure 7 by filled circles, while eyepiece interferometric and speckle data are indicated by filled and empty stars, respectively. On the other hand, $O - C$ lines connect measurements to their predicted locations on the

TABLE 7

Orbital Elements for BAG 10 Aa: Visual and Spectroscopic Orbits

Visual Orbit		Spectroscopic Orbit	
Parameter	Value[a]	Parameter	Value[b]
P (yr)..........	4.849 ± 0.050	P (yr)........................	4.84 ± 0.03
T.................	2003.504 ± 0.005	T...............................	1984.11 ± 0.10
e..................	0.224 ± 0.010	k_1 (km s^{-1})..............	10.5 ± 0.3
a (arcsec).....	0.0320 ± 0.0010	γ_0 (km s^{-1})..............	−8.7 ± 0.2
i (deg)..........	47.6 ± 3.0	e................................	0.23 ± 0.03
ω (deg)........	104.4 ± 7.0	ω_1 (deg)....................	290 ± 9
Ω (deg)........	329.9 ± 5.0[c]	$a_1 \sin i_{12}$ (10^8 km)....	2.56 ± 0.11

[a] Docobo & Andrade (2006).
[b] Cole et al. (1992).
[c] Ascending node.

TABLE 8

Measurements and $O - C$ Differences for BAG 10 Aa New Orbit

Epoch	θ (deg)	ρ (arcsec)	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)	Number of Nights	Observers[a]
1994.7180.......	162.5	0.0302	0.4	0.000	1	Sco
1994.7180.......	161.9	0.0302	−0.2	0.000	1	Sco
1994.7180.......	162.1	0.0296	0.0	−0.000	1	Sco
1994.7180.......	163.2	0.0291	1.1	−0.000	1	Sco
1998.7740.......	98.3	0.0200	−0.6	0.000	1	Bag
1998.7770.......	69.8	0.0160	−29.5[b]	−0.003	1	Bag

[a] Code for the original reference. Code format is the WDS Discoverer Designation code (usually the first three letters of the first author's name).

[b] Since this measurement has been made under the theoretical Rayleigh resolution limit for the 6.0 m telescope (~0″.020), it could be explain the large $O - C$ difference in θ.

orbit. The dashed line is the line of nodes. Orbits are shown in Figure 7.

5.1. *Hu 506 AB*

This binary ($m_v = 5.95$–6.84, B5 IV) was discovered by Hussey (1902). Two previous orbits of this pair had been simultaneously calculated by Docobo (2000), who obtained a period of 144.50 yr and a semimajor axis of 0″.201, and by Hartkopf (2000), with $P = 152.68$ yr and $a = 0''.203$. However, a new speckle measurement in 2004.9900 suggests a longer period. In this way, we have computed an improved orbit (Docobo & Andrade 2005). Orbital elements can be seen in Table 2, while the $O - C$ differences are listed in Table 6.

5.2. *BAG 10 Aa*

Bu 1099 AB is a quadruple system of hierarchy 3, where the widest binary has a period of 83.10 yr. Component B is a spectroscopic binary (Bab, Bc) with a period of 1769 days, whose first subcomponent is itself a spectroscopic binary (Ba, Bb) with a shorter period of 4.24 days. Moreover, component B is the first known case of a *speckle astrometric* binary.

Cole et al. (1992) calculated a combined speckle/spectroscopic orbit for this speckle astrometric component. They adopted P, T, e, and ω from the spectroscopic solution and determined the remaining elements (a, i, and Ω) by a grid search calculating rms residual errors at different increments in these orbital elements.

A few years ago this system was resolved by Schoeller et al. (1998) and Balega et al. (2002) by means of speckle interferometry. Because the previous orbit shows a very strong disagreement with these observations, we have calculated a visual orbit (see Table 7) taking into account the spectroscopic elements and the speckle measurements. The $O - C$ differences for this new orbit (Docobo & Andrade 2006) are shown in Table 8.

TABLE 9

Orbital Elements for LAB 6 Aa (Andrade 2006)

Parameter	Value
P (yr)	83 ± 9
T	1997.99 ± 0.10
e	0.732 ± 0.016
a (arcsec)....................	0.195 ± 0.008
i (deg).........................	87.3 ± 1.5
ω (deg)	194.6 ± 2.5
Ω (deg)......................	46.4 ± 1.5

TABLE 10

Measurements and $O - C$ Differences for LAB 6 Aa New Orbit

Epoch	θ (deg)	ρ (arcsec)	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)	Number of Nights	Observers[a]
1971.480..........	46.7	0.255	−1.3	−0.009	1	Lab
1971.480..........	47.7	0.256	−0.3	−0.008	1	Lab
1971.780..........	47.7	0.264	−0.3	0.002	1	Lab
1972.270..........	46.7	0.258	−1.3	−0.000	1	Lab
1972.270..........	46.7	0.262	−1.3	0.003	1	Lab
1972.460..........	46.7	0.252	−1.4	−0.005	1	Lab
1972.460..........	46.7	0.258	−1.4	0.000	1	Lab
1973.450..........	48.7	0.244	0.6	−0.006	1	Lab
1975.545..........	36.9	0.225	−11.4	−0.008	1	BLM
1975.631..........	46.7	0.242	−1.6	0.010	1	Bla
1975.715..........	49.2	0.234	0.9	0.003	1	McA
1975.773..........	47.7	0.247	−0.7	0.016	1	Bla
1975.956..........	47.1	0.210	−1.3	−0.019	1	BLM
1976.302..........	49.7	0.224	1.3	−0.002	1	McA
1976.401..........	53.8	0.242	5.4	0.017	1	Bla
1976.450..........	49.1	0.229	0.7	0.004	1	McA
1976.616..........	53.0	0.221	4.6	−0.002	1	McA
1976.619..........	49.9	0.234	1.5	0.011	1	McA
1976.622..........	49.7	0.226	1.3	0.003	1	McA
1976.859..........	49.0	0.222	0.5	0.000	1	McA
1977.482..........	48.6	0.217	0.0	0.002	1	McA
1977.487..........	48.5	0.218	−0.0	0.003	1	McA
1977.635..........	48.3	0.214	−0.2	0.000	1	McA
1977.674..........	49.8	0.250	1.2	0.036	1	Wgt
1977.881..........	47.0	0.204	−1.6	−0.008	1	BLM
1977.913..........	47.3	0.205	−1.3	−0.006	1	McA
1977.919..........	45.6	0.226	−3.0	0.015	1	McA
1978.395..........	50.8	0.233	2.2	0.026	1	Bnu
1978.541..........	49.4	0.206	0.7	0.000	1	McA
1978.610..........	49.4	0.204	0.7	−0.000	1	McA
1978.615..........	49.0	0.203	0.3	−0.001	1	McA
1979.469..........	50.8	0.204	2.0	0.008	1	Bnu
1979.530..........	48.3	0.201	−0.5	0.006	1	McA
1979.770..........	49.0	0.194	0.2	0.001	1	McA
1980.418..........	49.0	0.184	0.0	−0.002	1	Dud
1980.474..........	51.3	0.180	2.4	−0.005	1	Bag
1980.480..........	49.2	0.188	0.3	0.003	1	McA
1980.485..........	49.4	0.191	0.5	0.006	1	McA
1980.720..........	49.2	0.184	0.2	0.001	1	McA
1980.795..........	48.7	0.182	−0.3	0.000	1	Dud
1980.881..........	49.2	0.171	0.2	−0.010	1	McA
1980.895..........	49.5	0.195	0.5	0.014	1	McA
1981.465..........	50.4	0.172	1.3	−0.002	1	McA
1981.471..........	48.2	0.175	−0.9	0.000	1	McA
1982.503..........	48.4	0.159	−0.9	−0.003	1	McA
1982.506..........	49.6	0.153	0.3	−0.009	1	McA
1982.760..........	50.3	0.162	1.0	0.003	1	McA
1983.426..........	50.1	0.155	0.6	0.004	1	McA
1983.434..........	49.7	0.148	0.2	−0.003	1	McA
1983.710..........	50.8	0.150	1.2	0.002	1	McA
1984.701..........	50.2	0.133	0.4	−0.002	1	McA
1984.845..........	48.6	0.129	−1.3	−0.004	1	Bag
1985.485..........	50.7	0.123	0.6	−0.002	1	McA
1986.445..........	54.0	0.106	3.6	−0.005	1	Bla
1986.654..........	50.8	0.112	0.3	0.003	1	Bag
1986.891..........	52.4	0.100	1.8	−0.005	1	McA
1987.759..........	55.0	0.090	3.9	−0.003	1	McA
1988.663..........	50.9	0.068	−0.9	−0.011	1	McA
1990.755..........	49.2	0.050	−5.6	0.004	1	Hrt
1998.777..........	228.6	0.038	−0.6	−0.000	1	Bag
1998.777..........	229.7	0.039	0.5	0.000	1	Bag

[a] Code for the original reference. Code format is the WDS Discoverer Designation code (usually the first three letters of the first author's name).

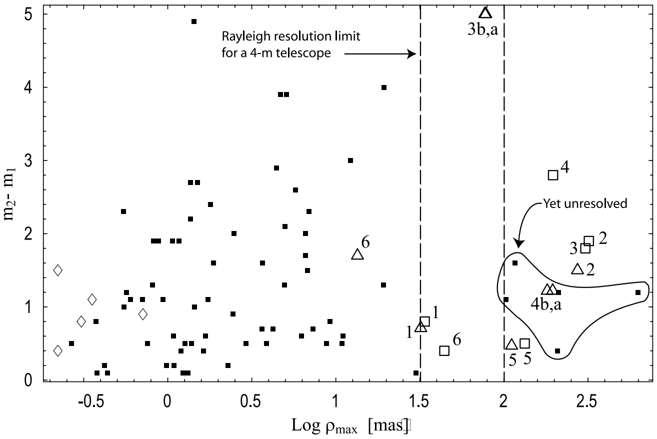

Fig. 8.—Distribution of spectroscopic binaries in the log $\rho_{\rm max}$–ΔM plane. As in Fig. 3, our results for the four VB-SBs are indicated by open numbered squares, while those of previous works are indicated by numbered triangles. All other spectroscopic binaries are indicated by small filled squares. On the other hand, eclipsing binaries, all of them near the left side, are indicated by diamonds. In addition, two vertical dashed lines suggest thresholds for optically resolving new spectroscopic binaries. Indeed, on the right side of the second dashed line there is a set of five SBs surrounded by a closed line; these are proposed as targets to be optically resolved.

The semimajor axis of the primary with regard to center of mass in astronomical units derived from our semimajor axis, our masses, and the *Hipparcos* parallax is $a_1 = 2.35 \pm 0.32$ AU. On the other hand, since we know from the spectroscopic orbit that $a_1 \sin i_{12} = (2.56 \pm 0.11) \times 10^8$ km, by considering our inclination we obtain $a_1 = 2.32 \pm 0.10$ AU. This strong agreement between both values shows that our orbital elements are completely compatible with those of the spectroscopic orbit.

5.3. *LAB 6 Aa*

This star ($m_v = 3.2$, B2 III) was observed as a binary by means of speckle interferometry in 1971 (Gezari et al. 1972). Some years later, a preliminary orbit was calculated by Pigulski & Boratyn (1992) by considering the light-time effect with $P = 91.6 \pm 3.7$ yr and $a = 0.''25 \pm 0.''07$. Since this orbit shows notable $O - C$ differences for the last two measurements in 1998.7770 (Balega et al. 2002) and negative trends in angular separation, Andrade (2006) has calculated a new orbit by using 61 speckle measurements. This orbit adjusts much better the passage by the periastron, giving more accurate orbital elements (see Table 9). The $O - C$ differences are listed in Table 10.

6. SPECTROSCOPIC BINARIES AS TARGETS TO BE OPTICALLY RESOLVED

Since we have calculated the probable fundamental parameters of a broad SB set, we could expect that some of them are near the optical resolution limit of the big telescopes. In fact, when we plot the absolute magnitude difference versus the maximum separation logarithm, we see that in the neighborhood of the pair of SB-VB 4, there are five SBs with similar parameters located at the right side of the second dashed line in Figure 8. Although such systems have never been seen before with optical techniques, we think that with appropriate monitoring they should turn out to be observable. Indeed, we propose them (see Table 11) as targets to be optically resolved. Such a task could be accomplished by means of speckle interferometry in large telescopes (see Fig. 9).

Moreover, there are still three SB systems with maximum angular separations between the Rayleigh resolution limit for a 10 m telescope (~12 mas) and 100 mas: STF 3062 B ($\rho_{\rm max} = 19.3$ mas and $\Delta m = 4.0$), Ho 581 A (19.2 mas and 1.3 mag), and SE 2 C (30.0 mas and 0.1 mag).

In any case, we cannot discard the possibility that these stars have not been observed for other reasons, for example, errors in the original data (spectral types, magnitudes, *Hipparcos* parallax, and/or orbital elements) or having degenerate stars as companions (probably white dwarfs according to the masses, all of them under the Chandrasekhar limit of 1.44 $\mathcal{M}_\odot$).

6.1. *STF 422 B*

Miura et al. (1993) and Hartkopf et al. (2000) tried to observe this spectroscopic binary by using interferometric techniques. However, they did not succeed in seeing their components separately. Their estimates for angular separation were smaller than $0.''06$ and $0.''035$, respectively.

Our results indicate that this binary should have a maximum angular separation of $0.''116 \pm 0.''069$ with a magnitude difference between the components of 1.6 ± 0.2 mag.

6.2. *HJ 2477 A*

This is the most surprising case of all. The only attempt at measurement was done by Balega et al. (1984). In 1982 they estimated that the angular separation for this system was smaller than $0.''028$. In contrast, we have calculated for maximum and minimum angular separation $0.''629 \pm 0.''082$ and $0.''233 \pm 0.''047$, respectively. We have also obtained a magnitude difference between the components of 1.2 ± 0.1 mag. In any case, by applying our methodology, we have found no compatible results for magnitude differences greater than 2.5 mag. Moreover, Halbwachs (1981) had already calculated a maximum nodal separation for this system of $0.''5$, in very good agreement with our results.

Currently, both components should present an angular separation of $0.''583$. With a period of 11.03 yr we expect that it will achieve its maximum separation in the middle of 2007.

6.3. *STF 1820 A*

For this SB there are no previous estimates of its angular separation. We have calculated a maximum angular separation of $0.''103 \pm 0.''018$ and a magnitude difference of 1.1 ± 0.1 mag.

TABLE 11
Targets to Try to Optically Resolve

WDS	Name	m_1	m_2	a_{12} (mas)	$\rho_{\rm max}$ (mas)	P_{12} (days)
03368+0035...............	STF 422 B	9.1 ± 0.1	10.7 ± 0.2	84 ± 48	116 ± 69	1152 ± 44
08592+4803...............	HJ 2477 A	3.4 ± 0.1	4.6 ± 0.1	484 ± 63	629 ± 82	4028 ± ...
14131+5520...............	STF 1820 A	9.4 ± 0.1	10.5 ± 0.1	62 ± 11	103 ± 18	1047.8 ± 5.7
17053+5428...............	STF 2130 B	6.0 ± 0.1	7.2 ± 0.1	148 ± 11	211 ± 16	2270 ± ...
20396+0458...............	Kui 99 A	8.9 ± 0.1	9.3 ± 0.1	121 ± 10	208 ± 17	920.2 ± 1.7

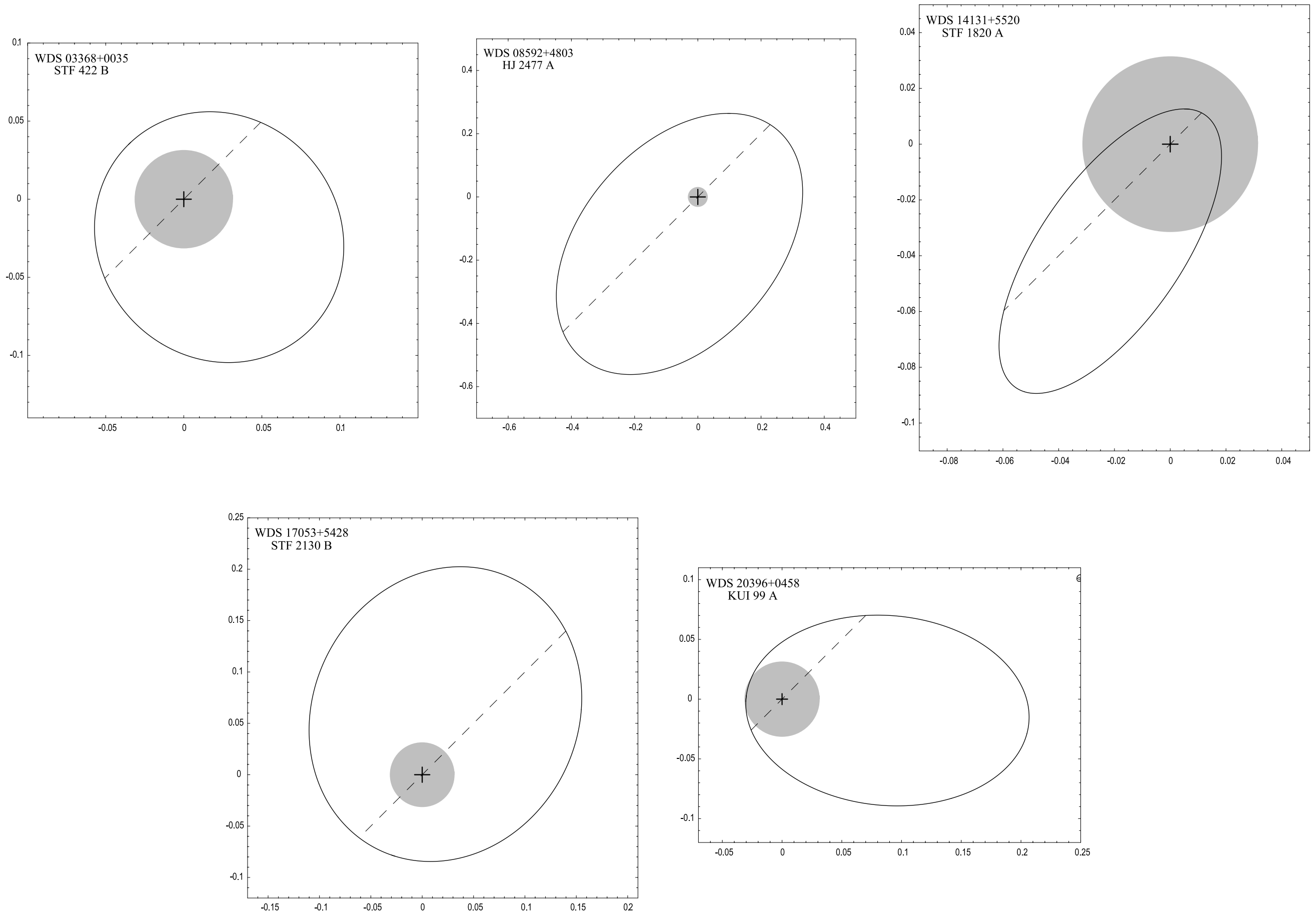

FIG. 9.—Probable apparent orbits for the spectroscopic subcomponents with wider orbits: STF 422 B, HJ 2477 A, STF 1820 A, STF 2130 B, and Kui 99 A (scale is in arcseconds). Disks show the Rayleigh resolution limit for a 4 m telescope.

6.4. *STF 2130 B*

The angular separation was estimated to be less than 0.″038 by McAlister et al. (1993) in 1988. We have calculated its maximum as 0.″211 ± 0.″016 and the magnitude difference as 0.8 ± 0.1 mag.

6.5. *Kui 99 A*

For this SB without previous interferometric measurements we have calculated a maximum angular separation of 0.″208 ± 0.″17 and a magnitude difference between components of 0.4 ± 0.1 mag.

7. CONCLUSIONS

On the basis of our study, the following conclusions can be drawn. Our methodology can be used to calculate reliable astrophysical and orbital parameters of spectroscopic subcomponents in multiple systems. Furthermore, in the case in which we are dealing with an SB2, we can adjust the absolute magnitude difference between spectroscopic components, taking into account that $q = \mathcal{M}_2/\mathcal{M}_1 = k_1/k_2$. In this way we can reach more precision than in an SB1 case, where we only have Jaschek's criterion. In fact, we do not discard the possibility that some of the results given for SB1 samples could be substantially improved.

We realize that some difficulties still remain. For example, there is a certain ambiguity in the assignment of the spectral types since there are some systems for which the methodology gives very compatible values whether the stars are giants, subgiants, or even main-sequence stars. Nevertheless, this problem can be overcome if we have information about spectral types, absolute magnitudes, or masses for some of the components.

We have seen that parallax plays a central role in the development of the methodology since its value, along with its error, determines strongly the results. In this sense, for consistency in the comparisons we have always taken the values given by *Hipparcos*. However, one can be free to take, in each case, the best available parallax.

Lastly, with speckle observations of the targets proposed in § 6, if the observations can really be achieved, new visual orbits could be calculated. In this case, the set of six VB-SBs that we have used to test this methodology would be substantially increased.

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