

SPECKLE INTERFEROMETRY AT MOUNT WILSON OBSERVATORY: OBSERVATIONS OBTAINED IN 2006–2007 AND 35 NEW ORBITS

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Received 2009 May 29; accepted 2009 June 28; published 2009 July 29

ABSTRACT

Results are presented for 607 speckle interferometric observations of double stars, as well as 222 measures of single stars or unresolved pairs. All data were obtained in 2006 and 2007 at the Mount Wilson Observatory, using the 2.5 m Hooker telescope. Separations range from $0''.06$ to $6''.31$, with a median of $0''.34$. These three observing runs concentrated on binaries in need of confirmation (mainly *Hipparcos* and *Tycho* pairs), as well as systems in need of improved orbital elements. New orbital solutions have been determined for 35 systems as a result.

Key words: binaries: general – binaries: visual – techniques: interferometric

Online-only material: color figures, machine-readable and VO tables

1. INTRODUCTION

Mount Wilson Observatory has been at the center of interferometric research for nearly all of its history, from the 20 foot beam used on the Hooker 100 inch telescope to measure the separations of close binary stars (Anderson 1920; Merrill 1921) and the first stellar diameter (Michelson & Pease 1921), to the Pease 50 foot interferometer, to multi-aperture instruments such as the Mark III (Shao et al. 1988), the Infrared Spatial Interferometer (Bloemhof et al. 1986), and the CHARA Array (McAlister et al. 2005). Also, the CHARA speckle camera was used at the 100 inch telescope shortly before that telescope's closure in 1985, then in a five-year series of observations following the telescope's reopening in 1993 (cf., Hartkopf et al. 1997).

The USNO speckle camera finally visited that hallowed ground for a run on the 100 inch in 2006 July, followed by runs in 2007 April and October. Results of those observing efforts, as well as new orbital elements derived in part from these new data, are presented below.

2. EQUIPMENT AND CALIBRATION

During equipment setup for our 2006 run, it was discovered that the ICCD for the USNO speckle camera had suffered a mechanical failure. Fortunately, the CHARA speckle camera (cf., Hartkopf et al. 2000) was in storage on the mountain, and despite eight years since its last use, this vintage-1991 ITT RS-170 detector (Mason et al. 1993b) worked immediately. After fabrication of a new cable, we were able to use this camera for the duration of the run; despite some time lost to clouds, 525 observations were obtained over six nights.

The speckle camera used for the two 2007 runs was described most recently in Mason et al. (2009). Data were obtained on 3.5 of six nights in April (446 observations) and on four of nine nights in October (569 observations). Time was lost in April due to high winds and snow, as well as ash from a major fire outbreak. Much of the October run was also lost due to Santa Anna winds and to ash from another major fire.

Absolute calibration of data for each run was obtained through the use of a slit mask mounted at the end of the telescope (see Figure 1). By observing a bright single star using this mask, an “artificial” double star is created, whose separation and position angle are defined by the slit spacing and orientation. Details of

the slit mask and calibration technique are given in Hartkopf et al. (1997).

3. RESULTS

A total of 607 new measures are given in Table 1, where Columns 1 and 2 give the Washington Double Star (WDS¹) and discoverer designations and Columns 3–5 list the epoch of observation (as fractional Besselian year), derived position angle (in degrees), and separation (in arcseconds). Poorer quality measures are indicated by a colon following θ and ρ . Column 6 lists the filter (Strömgren y , USNO g , or Johnson V) used in the observation; effective wavelength and FWHM values for these filters are listed at the end of the table.

For systems with published orbital elements in the *Sixth Catalog of Visual Orbits* (ORB6²), residuals in θ and ρ to that orbit are given in Columns 7 and 8, respectively. Column 9 gives a code for the orbit reference, based on the author's last name and the date of publication; all reference codes are included in the list of references below. Occasionally, ORB6 lists more than one “preferred” orbit, in which case residuals to both orbits are included. Also included in these columns are residuals to 35 new orbits, as described below and listed in Table 3. Coarse orbit grades (either as listed in ORB6 or calculated for the new solutions) are given in Column 10; these grades, on a scale of 1 (“definitive”) to 5 (“indeterminate”), are described by Hartkopf et al. (2001) and are based on similar grading schemes used in earlier orbit catalogs.

The final column flags notes to the observations. A “C” indicates that this is a confirming observation to a pair with only a single published measure in the WDS database. A “d” indicates that the new measure is quite different in θ ($> 30^\circ$) and/or ρ ($> 30\%$) from either the most recent published measure or the values predicted by the indicated published orbit. In many cases, these discrepancies are the result of orbital motion during the interval since the last observation; in other instances they indicate the need for an update of the orbital elements.

The 222 observations of 220 single stars and unresolved pairs are listed in Table 2. Here, Columns 1, 3, and 4 are the same as in Table 2. Column 2 lists either the discoverer designation

¹ <http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/WDS>

² <http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/orb6>

Report Documentation Page

Form Approved
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|--|------------------------------------|-------------------------------------|----------------------------|---|---------------------------------|
| 1. REPORT DATE MAY 2009 | | 2. REPORT TYPE | | 3. DATES COVERED 00-00-2009 to 00-00-2009 | |
| 4. TITLE AND SUBTITLE Speckle Interferometry at Mount Wilson Observatory: Observations Obtained in 2006-2007 and 35 New Orbits | | | | 5a. CONTRACT NUMBER | |
| | | | | 5b. GRANT NUMBER | |
| | | | | 5c. PROGRAM ELEMENT NUMBER | |
| 6. AUTHOR(S) | | | | 5d. PROJECT NUMBER | |
| | | | | 5e. TASK NUMBER | |
| | | | | 5f. WORK UNIT NUMBER | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Naval Observatory, 3450 Massachusetts Avenue NW, Washington, DC, 20392 | | | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | | | 10. SPONSOR/MONITOR'S ACRONYM(S) | |
| | | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited | | | | | |
| 13. SUPPLEMENTARY NOTES | | | | | |
| 14. ABSTRACT see report | | | | | |
| 15. SUBJECT TERMS | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT unclassified | b. ABSTRACT unclassified | c. THIS PAGE unclassified | | | |

Table 1
Speckle Interferometric Measurements

| WDS Desig. α, δ (2000) | Discoverer Designation | Epoch 2000.+ | θ ($^{\circ}$) | ρ ($''$) | Filt | $O-C$ (θ) | $O-C$ (ρ) | Orbit Reference | Orbit Grade | Note |
|---------------------------------------|---------------------------|-----------------|----------------------------|--------------------|------|-----------------------|---------------------|--------------------|----------------|------|
| 00002+4119 | TDS 1235 | 2007.8013 | 54.6 : | 1.208 : | V | | | | | C,d |
| 00021+5556 | TDS 1258 | 2007.7987 | 246.0 | 0.725 | V | | | | | C |
| 00121+5337 | BU 1026 AB | 2007.7987 | 310.0 | 0.323 | y | -0.7 | -0.009 | Har1996 | 2 | |
| 00134+2659 | STT 2 AB | 2007.8179 | 162.5 | 0.401 | y | 0.9 | 0.010 | Har2008 | 3 | |
| 00308+4732 | BU 394 | 2007.8013 | 275.3 | 0.544 | y | 0.4 | -0.027 | Zul1997 | 4 | |
| 00318+5431 | STT 12 | 2007.7987 | 205.1 | 0.287 | y | -2.4 | 0.084 | Lin2005 | 4 | d |
| 00335+4006 | HO 3 | 2007.8013 | 167.4 | 0.230 | y | 8.7 | -0.010 | Cve2006 | 3 | |
| 00339+5316 | TDS 1523 | 2007.7987 | 90.3 | 0.662 | V | | | | | C,d |
| 00441+5655 | TDS 1589 | 2007.7987 | 317.3 | 0.769 | V | | | | | C |
| 00456+5457 | TDS 1602 | 2007.7987 | 68.8 | 0.436 | V | | | | | C |

Notes. C: Confirming observation (only one published measure in WDS).

d: Large difference in θ ($> 30^{\circ}$) and/or ρ ($> 30\%$) compared with last published observation or orbit ephemeris.

q: Quadrant was flipped by 180° for the new orbit relative to the published one.

Filters: Strömgren γ ($\lambda_{\text{eff}} = 550$ nm, FWHM = 24 nm), USNO g (560/45 nm), Johnson V (545/ 85 nm).

Orbit grades: 1, “definitive;” 2, “good;” 3, “reliable;” 4, “preliminary;” 5, “indeterminate.” See *Sixth Orbit Catalog* for more details on orbit grading.

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)

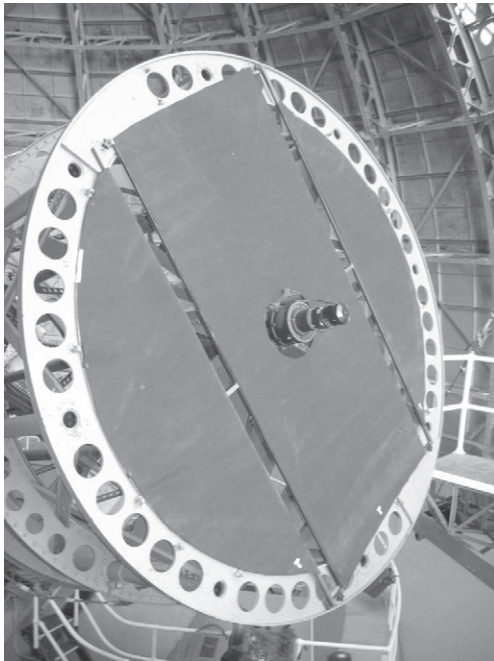


Figure 1. Slit mask mounted on the Hooker telescope. The slits themselves are rigid 3 m by 10 cm frames, constructed of square aluminum tubing; black canvas covers the remainder of the telescope opening. Slits are separated by 1.330 m, with exact positioning defined by multiple registration pins.

(as in Table 1) for a binary star, or the *Hipparcos* number for an object never resolved into a double. Column 5 gives rather more extensive notes to the object, as described at the end of the table. The most common note code is “U,” indicating a pair whose discovery observation (the date and separation of which are listed in parentheses) remains unconfirmed. References to the observation or orbit mentioned in the notes column are listed in Column 6.

4. NEW ORBITAL SOLUTIONS

New orbital solutions were attempted for all systems in Table 1 where recent measures showed considerable residuals from published elements. The “grid search” method used for

these calculations is described by Hartkopf et al. (1989), with the weighting system for individual observations described by Hartkopf et al. (2001). A total of 35 systems yielded new solutions which were deemed sufficiently improved for publication. Elements for these systems are given in Table 3, where Columns 1 and 2 give the WDS and discoverer designations and Columns 3–9 list the seven Campbell elements: P (period, in years), a (semimajor axis, in arcseconds), i (inclination, in degrees), Ω (longitude of node, equinox 2000, in degrees), T_0 (epoch of periastron passage, in fractional Besselian year), e (eccentricity), and ω (longitude of periastron, in degrees). Rough grades for each new orbital solution are given in Table 1, as for all other referenced orbits.

Figures 2–7 show the new orbital solutions, plotted with all published data in the WDS database. In each of these figures, micrometric observations are indicated by plus signs, interferometric measures by filled circles or (for the new USNO measures) filled stars, *Hipparcos* and *Tycho* measures by the letters “H” or “T.” “ $O-C$ ” lines connect each measure to its predicted position along the new orbit (shown as a thick solid line). A dot-dashed line indicates the line of nodes, and a curved arrow in the lower right corner of each figure indicates the direction of orbital motion. Finally, the previous published orbit is shown as a dashed ellipse; references to each of the published orbits are given in Column 9 of Table 1.

A note about orbit grading is perhaps in order. Of the 35 pairs with new orbital solutions, one saw an improvement by two numeric grades and 14 by one grade. Another 18 were unchanged (at least to the nearest integer grade) and the remaining two saw their grade fall from 4 to 5. These last two systems perhaps illustrate the limitations of reducing a quasi-subjective determination of orbit quality to a numeric formula. The grade is based on a number of factors, including number of observations, mean orbit residuals, phase coverage, etc. (see the ORB6 webpage for a more complete discussion of the procedure used). For these two pairs (09591+5316 and 21047+0332), a glance at the figures shows that the new orbits obviously provide a better fit to the data than the solutions published two decades ago. However, these new solutions are of considerably longer period than the earlier fits, thus decreasing the phase coverage by these data and consequently lowering the calculated orbit grades. Although on

Table 2
Unresolved Objects

| WDS α, δ (2000) | Disc. Designation or HIP | Epoch | Filt | Note | Reference |
|--------------------------------|-----------------------------|-----------|------|-----------------------|-----------|
| 00124+4558 | HDS 27 | 2007.8013 | y | U (1991, 0'12) | HIP1997a |
| 00240+4912 | HDS 55 | 2007.8013 | y | U (1991, 0'17) | HIP1997a |
| 00292+4043 | TDS 1488 | 2007.8013 | V | U (1991, 0'47) | Fab2002 |
| 00394+2115 | HIP 3093 | 2007.8179 | y | W (54 Psc = STT 550A) | |
| 00542+4318 | COU 1654 | 2007.8014 | g | C (orbit: 0'042) | Sey2002 |
| 00586+4153 | TDS 1697 AB | 2007.8014 | V | U (1991, 0'42) | Fab2002 |
| 01014+4900 | TDS 1721 | 2007.8013 | V | U (1991, 0'47) | Fab2002 |
| 01016+3318 | TDS 1727 | 2007.8179 | y | U (1991, 0'37) | Fab2002 |
| 01021+3658 | TDS 1731 | 2007.8179 | V | U (1991, 0'58) | Fab2002 |
| 01072+4933 | HDS 145 | 2007.8013 | y | U (1991, 0'13) | HIP1997a |

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)

the whole, the numerical grading formula reproduces the subjective grades of earlier orbit catalogs reasonably well (and can perhaps track incremental improvements in orbit quality fairly accurately), the eye and brain are still superior in judging more substantial changes in orbital fits.

Table 4 gives ephemerides for each new orbit over the years 2010 through 2020, in two-year increments. Columns 1 and 2 are the same identifiers as in the previous table, while Columns (3+4), (5+6),... (13+14) give predicted values of θ and ρ , respectively, for the years 2010.0, 2012.0, etc., through 2020.0.

5. NOTES TO INDIVIDUAL ORBIT SYSTEMS

01014+3535 = COU 854. The mass sum predicted from these elements is about $3.4 \pm 2.4 M_{\odot}$; the value is about 40% too high for this pair of F8 dwarfs, but the large formal errors make this difference of little consequence.

01443+5732 = BU 870 AB. A nearby companion (separation 13") was discovered in 1916 (Guillaume 1931) but never confirmed; perhaps it is lost in the glare of the bright primary. A 10th magnitude star 2.7 arcminutes from BU 870 was discovered by Arnold (2004) to share common proper motion; relative astrometry subsequently gleaned from *Tycho* and the Two Micron All Sky Survey (2MASS), as well as archival astrographic plates dating as far back as 1910, confirms that the stars' relative position remains unchanged.

01570+3101 = A 819 AB. A 10th magnitude companion at 66" shares common proper motion with this close pair, and is probably physical.

02517+4559 = A 1281. A high proper motion system; the primary is of spectral type G5V, and based on the magnitude difference the secondary is probably an early-K dwarf.

02586+2408 = BU 1173 AB. The 13th magnitude C component at 4".6 is probably physical.

03423+3141 = COU 691. The pair consists of two equal-magnitude F8 dwarfs. Due to their fairly eccentric, inclined orbit, the stars reached a minimum separation of about 14 mas in early 2004, which would have required a 10 m class telescope for resolution.

03463+2411 = BU 536 AB. The relative motion of these two Pleiades stars can be fitted perhaps equally well by assuming that they are an optical pair in rectilinear motion. Their close proximity argues for physicality, although their location within a cluster somewhat lessens the strength of that argument.

03484+5202 = HU 546. The primary is listed as G6IV in SIMBAD; the small magnitude difference suggests the secondary is also G6IV or slightly later. These elements, coupled with a *Hipparcos* parallax of 19.75 ± 2.97 mas, yield a mass sum of about $1.1 \pm 0.5 M_{\odot}$ —about a factor of 2 too small. However, given the large parallax uncertainty, this can be resolved by a decrease in π of only 1.2σ .

04262+3544 = HU 608. A pair of F8 dwarfs; the large formal errors for the elements make any mass estimate meaningless for this system.

06323+5225 = WOR 6. GJ 235 consists of two M0 dwarfs; at an estimated distance of about 20pc (Johnson & Wright 1983), these orbital elements yield a mass sum of about 2.1 solar masses, about a factor of 2 too high. Unfortunately, no *Hipparcos* or other recent parallax data are available.

06532+3826 = COU 1877. NLTT 17106 = 60 Aur consists of an F5V primary and a secondary of spectral type about K0 (based on magnitude difference). The mass sum resulting from this orbit ($1.9 M_{\odot}$) is much more reasonable than might be expected, given the large errors in the elements.

07560+2342 = COU 929. The high proper motion pair NLTT 18641 = G 91-20 was first resolved by lunar occultation in 1970 (de Veigt & Gehlich 1976), then by micrometry a few years later (Couteau 1973). The spectral type of the primary is listed as G0; based on the *Hipparcos* magnitude difference the secondary is about G5. These orbital elements, combined with the *Hipparcos* parallax (15.93 ± 0.90 mas) predict a mass sum of $2.03 \pm 0.36 M_{\odot}$, in quite good agreement.

09591+5316 = A 1346. An F8V primary and ~G2 secondary; the predicted mass sum of $4.7 \pm 2.7 M_{\odot}$ is about a factor of 2 too high.

12268-0536 = A 78. This pair has nearly completed one full revolution since its discovery by Aitken (1900). The primary is an F4V, the secondary approximately F8/G0. The mass sum estimated from this solution is $2.8 \pm 1.0 M_{\odot}$, in reasonable agreement for these types.

14122+4411 = STT 278. Spectral types are F2IV and perhaps either F5IV or a late-A dwarf. The predicted mass sum ($1.6 \pm 0.7 M_{\odot}$) looks to be an underestimate.

15031+4439 = CHR 43. This pair was discovered in 1985 at the Canada–France–Hawaii Telescope (CFHT) 3.6 m, during a speckle duplicity survey of stars in the Yale *Bright Star Catalogue* (McAlister et al. 1987b), as were fellow Table 3 entries $15513-0305 = CHR 51$ and $22383+4511 = CHR 114$.

Table 3
New Orbital Elements

| WDS (Figure No.) | Discoverer Designation | | P (yr) | a ($''$) | i ($^{\circ}$) | Ω ($^{\circ}$) | T_o (yr) | e | ω ($^{\circ}$) |
|---------------------|---------------------------|---------|----------------------|-------------------|-----------------------|----------------------------|----------------------|-------------------|----------------------------|
| 00520+3154 (2a) | A | 924 | 182.57 \pm 16.74 | 0.296 \pm 0.001 | 154.2 \pm 6.2 | 44.8 \pm 18.1 | 1986.54 \pm 0.53 | 0.704 \pm 0.021 | 318.2 \pm 17.6 |
| 01014+3535 (2b) | COU | 854 | 68.11 \pm 3.71 | 0.149 \pm 0.005 | 150.4 \pm 7.7 | 221.1 \pm 10.4 | 1999.59 \pm 4.24 | 0.123 \pm 0.022 | 127.0 \pm 21.4 |
| 01443+5732 (2c) | BU | 870 AB | 193.17 \pm 6.23 | 0.899 \pm 0.012 | 134.8 \pm 3.8 | 128.8 \pm 4.6 | 2022.39 \pm 0.78 | 0.773 \pm 0.016 | 270.2 \pm 7.4 |
| 01570+3101 (2d) | A | 819 AB | 164.18 \pm 32.89 | 0.437 \pm 0.025 | 48.6 \pm 4.0 | 170.6 \pm 10.6 | 2010.04 \pm 1.63 | 0.462 \pm 0.076 | 149.7 \pm 31.5 |
| 02517+4559 (2e) | A | 1281 | 146.40 \pm 5.03 | 0.491 \pm 0.006 | 42.0 \pm 2.8 | 161.0 \pm 4.0 | 1936.37 \pm 1.45 | 0.328 \pm 0.017 | 148.4 \pm 6.4 |
| 02586+2408 (2f) | BU | 1173 AB | 296.96 \pm 69.00 | 0.377 \pm 0.001 | 76.6 \pm 1.7 | 105.5 \pm 2.7 | 2029.02 \pm 3.10 | 0.607 \pm 0.058 | 70.6 \pm 9.9 |
| 03423+3141 (3a) | COU | 691 | 35.07 \pm 1.31 | 0.184 \pm 0.037 | 76.1 \pm 20.8 | 241.1 \pm 7.6 | 2004.10 \pm 3.02 | 0.685 \pm 0.317 | 75.5 \pm 40.7 |
| 03463+2411 (3b) | BU | 536 AB | 885.64 \pm 385.32 | 1.211 \pm 0.124 | 99.3 \pm 2.3 | 175.3 \pm 0.7 | 1877.90 \pm 73.36 | 0.314 \pm 0.002 | 245.5 \pm 62.5 |
| 03484+5202 (3c) | HU | 546 | 69.37 \pm 0.49 | 0.344 \pm 0.005 | 148.2 \pm 2.9 | 264.3 \pm 4.6 | 1973.87 \pm 0.95 | 0.173 \pm 0.012 | 51.3 \pm 8.1 |
| 04262+3544 (3d) | HU | 608 | 459.08 \pm 978.17 | 0.617 \pm 0.239 | 135.5 \pm 53.1 | 188.5 \pm 7.3 | 1888.00 \pm 120.62 | 0.350 \pm 0.028 | 352.4 \pm 244.0 |
| 04400+2301 (3e) | HU | 442 | 140.23 \pm 3.67 | 0.260 \pm 0.017 | 28.1 \pm 9.4 | 165.6 \pm 21.1 | 1997.53 \pm 0.98 | 0.716 \pm 0.017 | 3.9 \pm 24.8 |
| 06323+5225 (3f) | WOR | 6 | 53.57 \pm 1.41 | 0.913 \pm 0.020 | 111.4 \pm 1.4 | 110.7 \pm 1.4 | 1980.55 \pm 0.13 | 0.766 \pm 0.006 | 102.6 \pm 2.1 |
| 06532+3826 (4a) | COU | 1877 | 271.10 \pm 61.00 | 0.793 \pm 0.073 | 58.4 \pm 5.4 | 156.4 \pm 7.0 | 2002.72 \pm 6.07 | 0.487 \pm 0.090 | 59.7 \pm 19.9 |
| 07303+4959 (4b) | STF | 1093 | 1190.95 \pm 529.46 | 1.320 \pm 0.174 | 41.2 \pm 15.9 | 125.4 \pm 12.7 | 1850.91 \pm 42.26 | 0.470 \pm 0.057 | 336.9 \pm 35.9 |
| 07560+2342 (4c) | COU | 929 | 44.43 \pm 0.32 | 0.253 \pm 0.003 | 71.5 \pm 0.4 | 187.3 \pm 0.3 | 1953.65 \pm 0.29 | 0.472 \pm 0.003 | 71.5 \pm 1.1 |
| 09591+5316 (4d) | A | 1346 | 298.13 \pm 22.83 | 0.560 \pm 0.045 | 110.0 \pm 1.9 | 175.9 \pm 1.6 | 1971.51 \pm 1.32 | 0.742 \pm 0.020 | 208.4 \pm 2.9 |
| 12268–0536 (4e) | A | 78 | 111.93 \pm 1.72 | 0.263 \pm 0.005 | 49.3 \pm 2.2 | 249.9 \pm 3.2 | 1997.50 \pm 0.40 | 0.798 \pm 0.008 | 42.1 \pm 4.9 |
| 14122+4411 (4f) | STT | 278 | 506.77 \pm 15.01 | 0.518 \pm 0.008 | 149.9 \pm 2.1 | 8.5 \pm 6.4 | 1948.42 \pm 1.67 | 0.434 \pm 0.010 | 355.7 \pm 4.5 |
| 15031+4439 (5a) | CHR | 43 | 170.88 \pm 8.91 | 0.626 \pm 0.047 | 73.9 \pm 2.8 | 222.2 \pm 4.9 | 1999.39 \pm 2.81 | 0.586 \pm 0.028 | 347.1 \pm 13.2 |
| 15206+1523 (5b) | HU | 1160 | 177.74 \pm 11.99 | 1.111 \pm 0.021 | 55.2 \pm 4.5 | 39.4 \pm 5.2 | 2004.84 \pm 1.20 | 0.709 \pm 0.028 | 10.1 \pm 11.3 |
| 15347+2655 (5c) | COU | 798 | 216.23 \pm 61.54 | 0.305 \pm 0.072 | 64.0 \pm 4.8 | 49.7 \pm 4.4 | 1987.11 \pm 3.71 | 0.494 \pm 0.122 | 35.9 \pm 11.6 |
| 15513–0305 (5d) | CHR | 51 | 44.60 \pm 1.20 | 0.199 \pm 0.000 | 118.0 \pm 0.9 | 90.4 \pm 1.8 | 1994.12 \pm 0.21 | 0.806 \pm 0.008 | 52.9 \pm 1.2 |

Table 3
(Continued.)

| WDS (Figure No.) | Discoverer Designation | P (yr) | a ($''$) | i ($^{\circ}$) | Ω ($^{\circ}$) | T_o (yr) | e | ω ($^{\circ}$) |
|---------------------|---------------------------|--------------------|-------------------|-----------------------|----------------------------|---------------------|-------------------|----------------------------|
| 16085–1006 (5e) | BU 949 | 54.88 ± 0.21 | 0.363 ± 0.002 | 84.8 ± 0.6 | 199.9 ± 0.1 | 1903.73 ± 0.20 | 0.847 ± 0.010 | 131.4 ± 1.5 |
| 16216+3631 (5f) | COU 982 | 88.30 ± 6.94 | 0.380 ± 0.024 | 62.1 ± 2.2 | 74.3 ± 3.1 | 2000.49 ± 0.56 | 0.490 ± 0.028 | 43.5 ± 4.0 |
| 17255+0030 (6a) | RST 5432 | 93.98 ± 4.89 | 0.285 ± 0.011 | 141.6 ± 5.6 | 149.2 ± 9.5 | 1998.34 ± 1.97 | 0.274 ± 0.024 | 228.5 ± 15.3 |
| 18018+0118 (6b) | BU 1125 AB | 175.74 ± 4.65 | 1.090 ± 0.027 | 69.5 ± 3.0 | 160.2 ± 1.6 | 2019.87 ± 1.48 | 0.831 ± 0.035 | 78.9 ± 4.7 |
| 18043+4206 (6c) | COU 1786 | 56.97 ± 9.62 | 0.148 ± 0.015 | 42.3 ± 2.9 | 202.1 ± 9.0 | 2045.61 ± 10.85 | 0.304 ± 0.068 | 332.8 ± 6.8 |
| 20210+4437 (6d) | A 725 | 166.85 ± 7.08 | 0.715 ± 0.021 | 65.7 ± 1.7 | 226.4 ± 0.9 | 1959.85 ± 0.97 | 0.494 ± 0.021 | 341.4 ± 2.5 |
| 20330+4950 (6e) | MCA 61 | 184.75 ± 33.29 | 0.133 ± 0.016 | 46.0 ± 3.8 | 219.5 ± 4.5 | 1986.09 ± 0.66 | 0.612 ± 0.045 | 266.7 ± 4.8 |
| 21047+0332 (6f) | SE 3 BC | 654.22 ± 99.48 | 1.342 ± 0.173 | 61.2 ± 3.7 | 162.4 ± 4.1 | 1971.46 ± 10.02 | 0.424 ± 0.078 | 250.2 ± 7.7 |
| 21147–0050 (7a) | A 883 AB | 81.11 ± 0.78 | 0.167 ± 0.003 | 126.8 ± 1.8 | 116.6 ± 2.8 | 1946.27 ± 2.14 | 0.170 ± 0.013 | 260.9 ± 11.3 |
| 22075+2538 (7b) | A 308 | 174.38 ± 8.71 | 0.200 ± 0.004 | 68.4 ± 2.0 | 305.7 ± 1.5 | 2015.31 ± 20.58 | 0.059 ± 0.024 | 26.1 ± 47.7 |
| 22375+2356 (7c) | HU 391 AB | 132.11 ± 6.52 | 0.613 ± 0.030 | 49.3 ± 14.0 | 163.2 ± 10.1 | 2010.44 ± 2.18 | 0.783 ± 0.079 | 214.2 ± 16.3 |
| 22383+4511 (7d) | CHR 114 | 35.70 ± 1.56 | 0.146 ± 0.000 | 62.8 ± 1.3 | 83.9 ± 1.5 | 2013.07 ± 0.78 | 0.489 ± 0.048 | 281.4 ± 0.9 |
| 23019+4220 (7e) | WRH 37 AB | 65.61 ± 4.57 | 0.250 ± 0.009 | 107.1 ± 3.0 | 191.8 ± 2.7 | 1946.46 ± 6.37 | 0.523 ± 0.052 | 32.0 ± 17.5 |

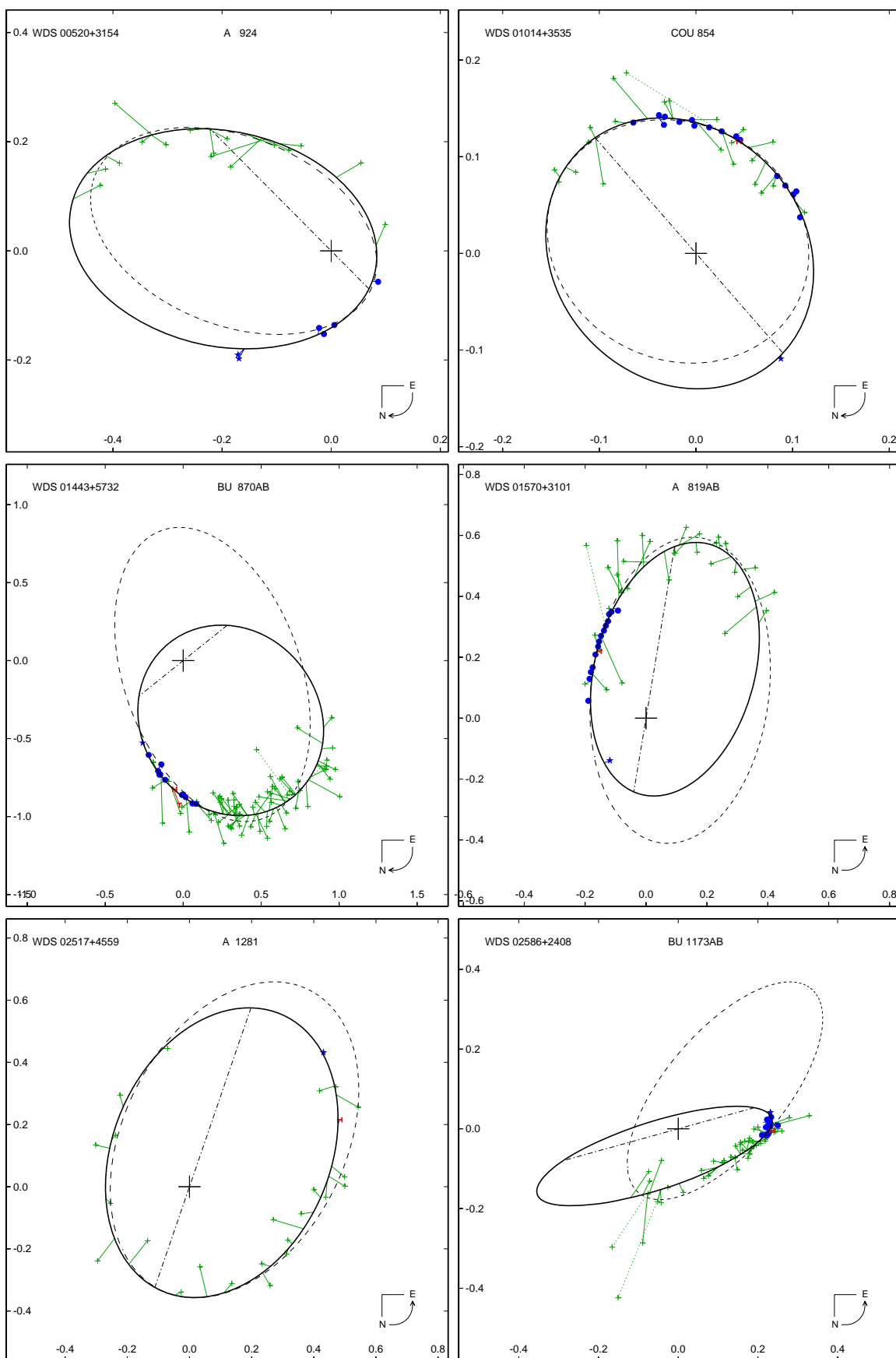


Figure 2. New orbits for the systems listed in Table 3, together with the most recent published elements for these systems and all published data in the WDS database. See the text for a description of symbols used in this and the following figures.

(A color version of this figure is available in the online journal.)

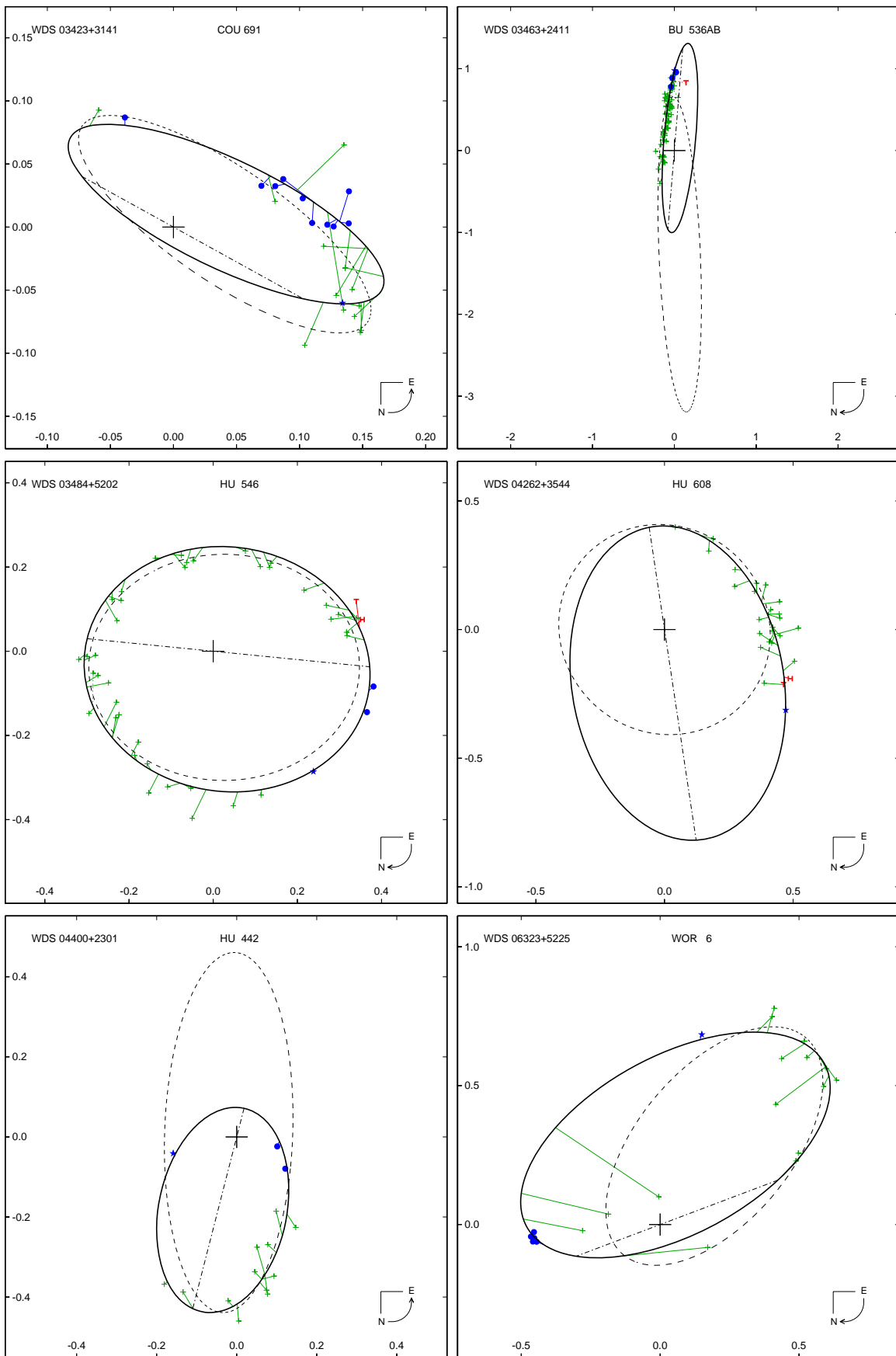


Figure 3. New orbits (continued).
(A color version of this figure is available in the online journal.)

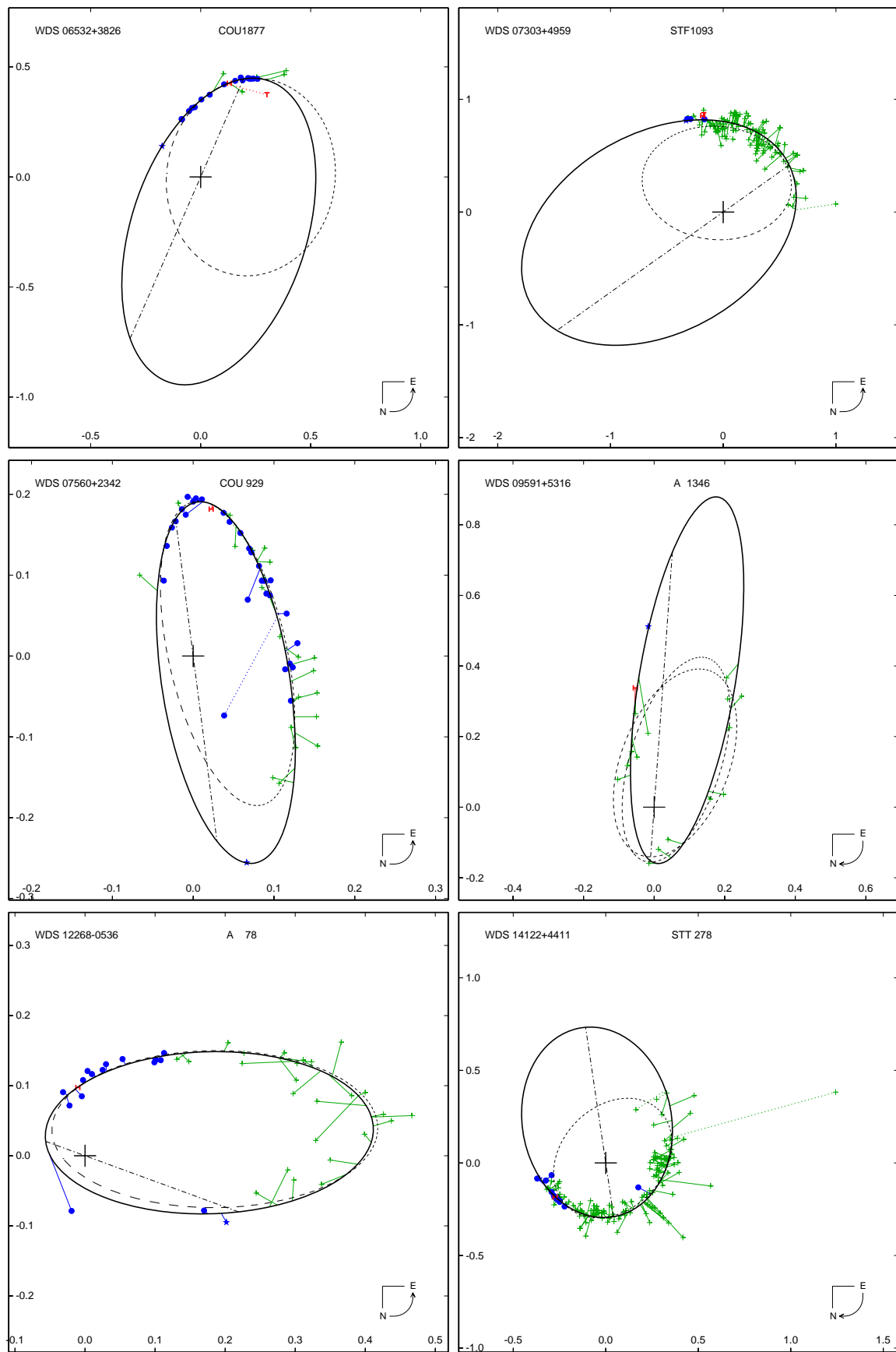


Figure 4. New orbits (continued).
(A color version of this figure is available in the online journal.)

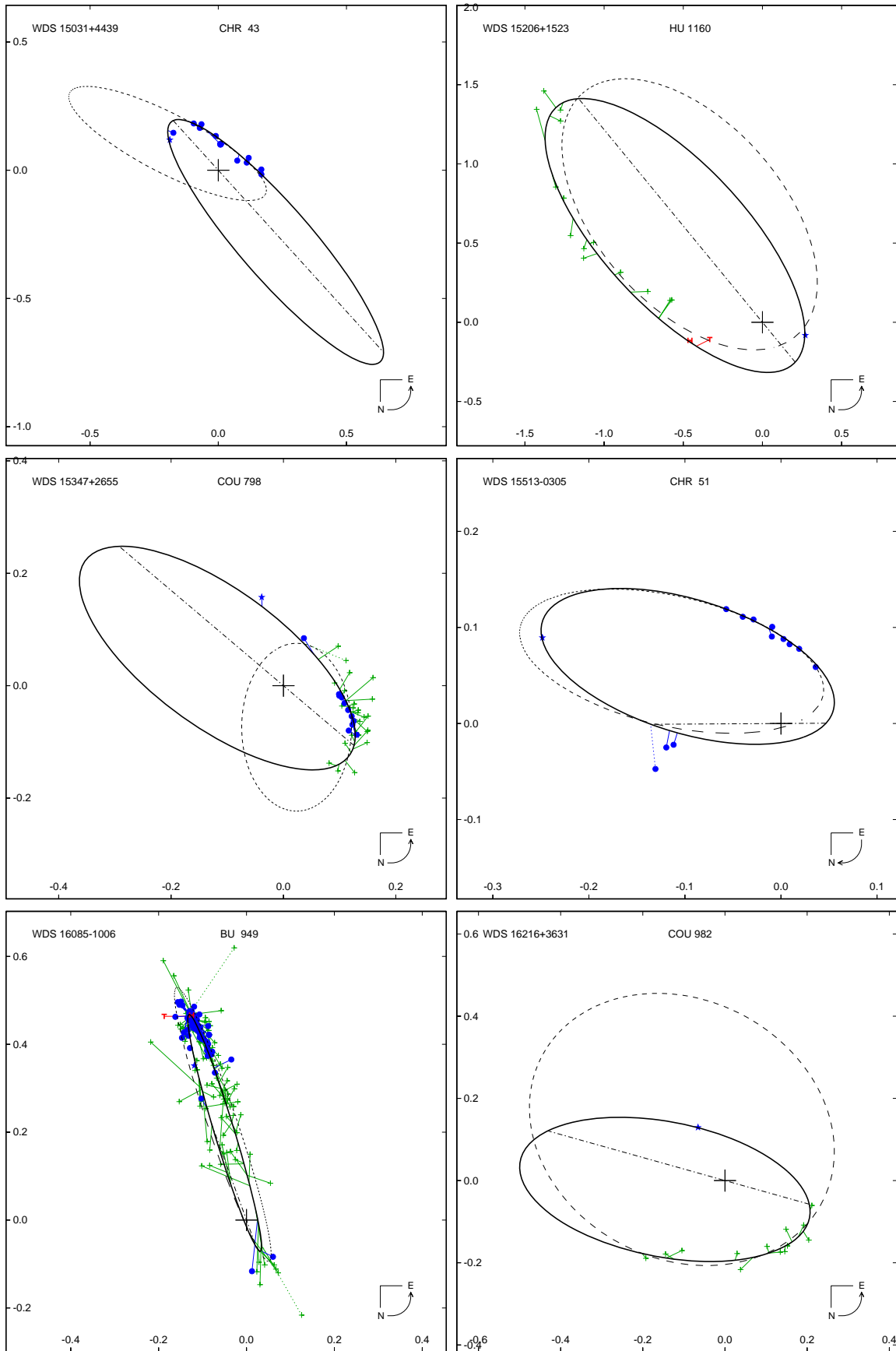


Figure 5. New orbits (continued).
(A color version of this figure is available in the online journal.)

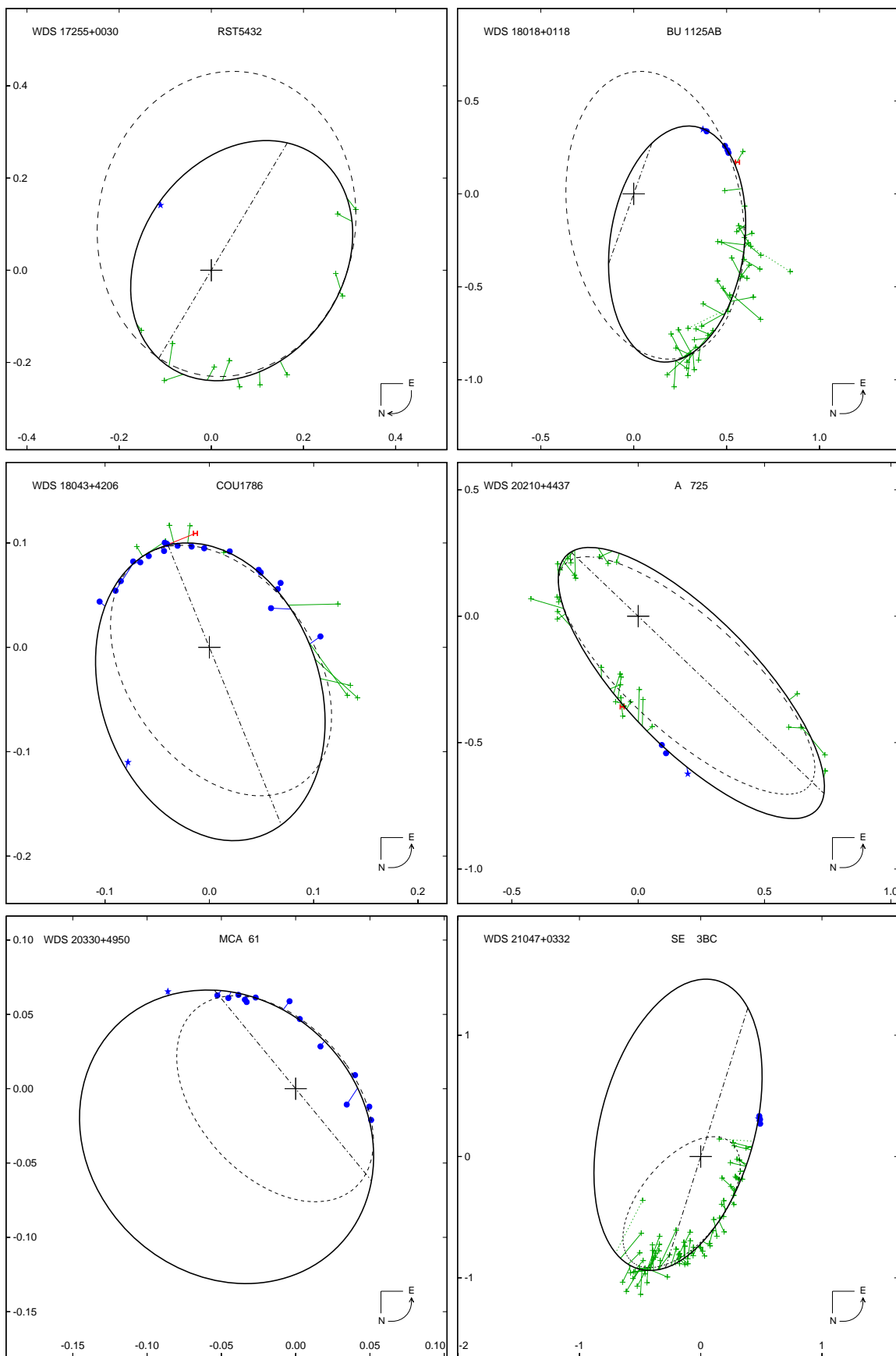


Figure 6. New orbits (continued).
(A color version of this figure is available in the online journal.)

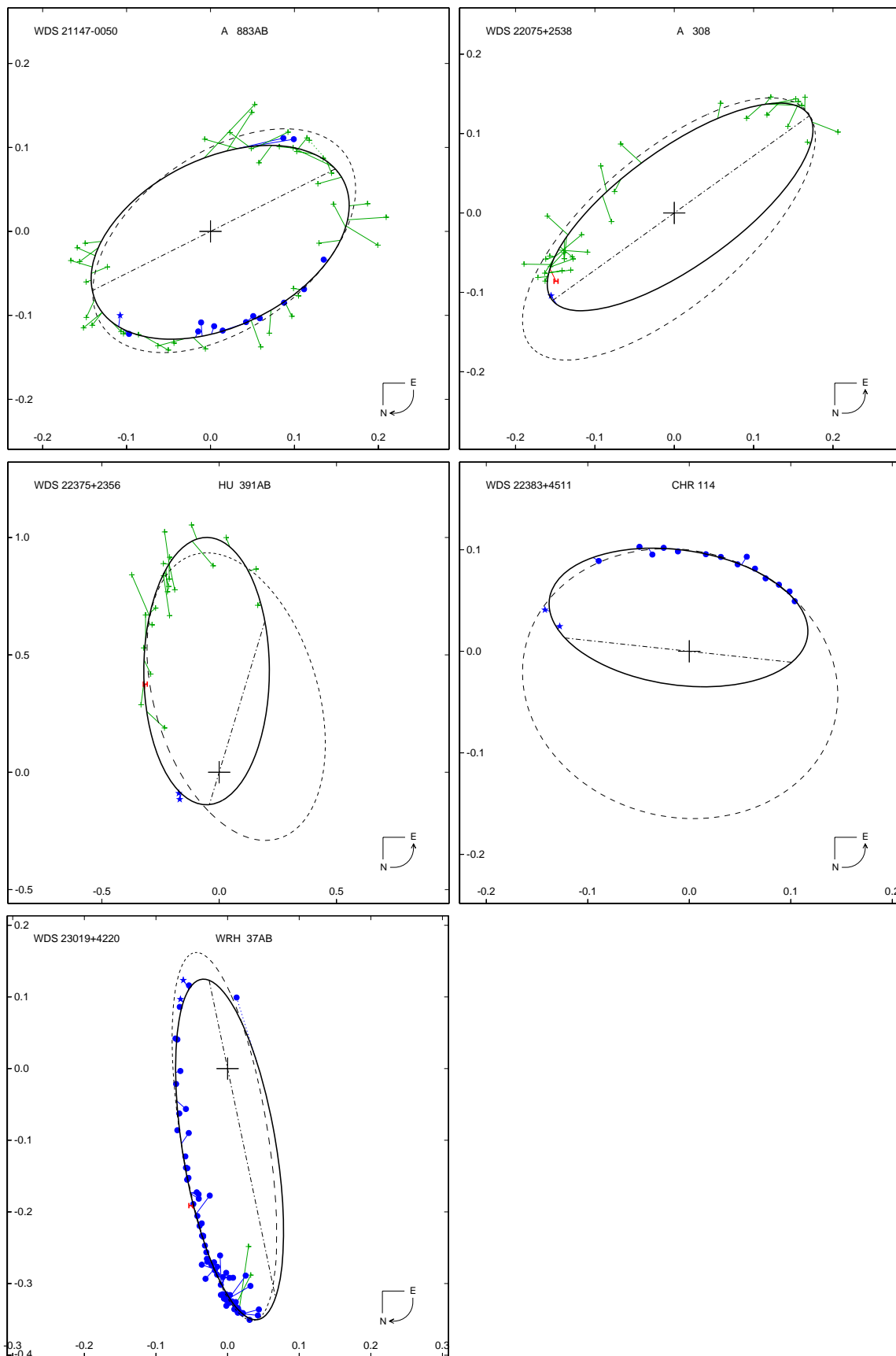


Figure 7. New orbits (continued).
(A color version of this figure is available in the online journal.)

Table 4
Orbital Ephemerides

| WDS | Discoverer | | 2010.0 | | 2012.0 | | 2014.0 | | 2016.0 | | 2018.0 | | 2020.0 | |
|------------|------------|---------|----------------|----------|----------------|----------|----------------|----------|----------------|----------|----------------|----------|----------------|----------|
| | | | θ° | ρ'' | θ° | ρ'' | θ° | ρ'' | θ° | ρ'' | θ° | ρ'' | θ° | ρ'' |
| 00520+3154 | A | 924 | 314.5 | 0.255 | 311.2 | 0.268 | 308.3 | 0.281 | 305.6 | 0.294 | 303.1 | 0.305 | 300.9 | 0.317 |
| 01014+3535 | COU | 854 | 28.3 | 0.139 | 17.9 | 0.140 | 7.6 | 0.140 | 357.3 | 0.140 | 346.9 | 0.140 | 336.5 | 0.140 |
| 01443+5732 | BU | 870 AB | 329.7 | 0.542 | 324.7 | 0.493 | 318.4 | 0.438 | 310.2 | 0.374 | 298.2 | 0.298 | 277.0 | 0.212 |
| 01570+3101 | A | 819 AB | 329.2 | 0.217 | 339.0 | 0.231 | 347.7 | 0.242 | 355.8 | 0.251 | 3.4 | 0.256 | 10.8 | 0.259 |
| 02517+4559 | A | 1281 | 136.9 | 0.612 | 139.1 | 0.618 | 141.3 | 0.623 | 143.5 | 0.626 | 145.6 | 0.629 | 147.7 | 0.630 |
| 02586+2408 | BU | 1173 AB | 101.8 | 0.221 | 103.2 | 0.213 | 104.6 | 0.204 | 106.3 | 0.193 | 108.1 | 0.179 | 110.3 | 0.162 |
| 03423+3141 | COU | 691 | 70.7 | 0.169 | 74.8 | 0.173 | 78.9 | 0.167 | 83.5 | 0.156 | 89.1 | 0.140 | 96.2 | 0.122 |
| 03463+2411 | BU | 536 AB | 179.7 | 0.982 | 179.5 | 0.994 | 179.4 | 1.007 | 179.2 | 1.019 | 179.0 | 1.031 | 178.8 | 1.042 |
| 03484+5202 | HU | 546 | 32.1 | 0.362 | 24.1 | 0.353 | 15.6 | 0.345 | 6.8 | 0.337 | 357.5 | 0.330 | 347.9 | 0.324 |
| 04262+3544 | HU | 608 | 55.3 | 0.572 | 54.1 | 0.580 | 52.9 | 0.588 | 51.8 | 0.595 | 50.7 | 0.603 | 49.6 | 0.610 |
| 04400+2301 | HU | 442 | 293.4 | 0.183 | 299.2 | 0.204 | 303.8 | 0.224 | 307.8 | 0.242 | 311.2 | 0.260 | 314.1 | 0.276 |
| 06323+5225 | WOR | 6 | 161.9 | 0.718 | 157.0 | 0.751 | 152.6 | 0.780 | 148.4 | 0.805 | 144.4 | 0.824 | 140.6 | 0.835 |
| 06532+3826 | COU | 1877 | 247.8 | 0.224 | 262.4 | 0.237 | 274.9 | 0.260 | 285.1 | 0.290 | 293.2 | 0.325 | 299.7 | 0.361 |
| 07303+4959 | STF | 1093 | 201.9 | 0.874 | 202.8 | 0.879 | 203.7 | 0.883 | 204.6 | 0.887 | 205.5 | 0.891 | 206.4 | 0.896 |
| 07560+2342 | COU | 929 | 19.2 | 0.267 | 23.4 | 0.258 | 28.0 | 0.241 | 33.5 | 0.219 | 40.3 | 0.194 | 49.3 | 0.167 |
| 09591+5316 | A | 1346 | 180.9 | 0.538 | 180.3 | 0.558 | 179.8 | 0.577 | 179.3 | 0.596 | 178.8 | 0.614 | 178.4 | 0.631 |
| 12268-0536 | A | 78 | 71.5 | 0.247 | 74.1 | 0.270 | 76.4 | 0.290 | 78.3 | 0.309 | 80.0 | 0.325 | 81.6 | 0.339 |
| 14122+4411 | STT | 278 | 280.5 | 0.371 | 278.4 | 0.376 | 276.3 | 0.381 | 274.3 | 0.387 | 272.3 | 0.392 | 270.4 | 0.398 |
| 15031+4439 | CHR | 43 | 256.2 | 0.172 | 271.0 | 0.146 | 290.8 | 0.130 | 313.0 | 0.131 | 332.3 | 0.148 | 346.5 | 0.177 |
| 15206+1523 | HU | 1160 | 111.3 | 0.261 | 137.8 | 0.299 | 156.3 | 0.368 | 168.5 | 0.451 | 176.8 | 0.537 | 182.8 | 0.624 |
| 15347+2655 | COU | 798 | 201.5 | 0.170 | 205.2 | 0.188 | 208.2 | 0.206 | 210.8 | 0.222 | 213.0 | 0.238 | 215.0 | 0.253 |
| 15513-0305 | CHR | 51 | 246.6 | 0.270 | 244.2 | 0.269 | 241.7 | 0.265 | 239.1 | 0.257 | 236.3 | 0.247 | 233.2 | 0.233 |
| 16085-1006 | BU | 949 | 199.7 | 0.247 | 202.3 | 0.125 | 21.2 | 0.072 | 39.9 | 0.051 | 126.3 | 0.028 | 172.5 | 0.072 |
| 16216+3631 | COU | 982 | 231.0 | 0.239 | 237.9 | 0.290 | 242.9 | 0.335 | 246.7 | 0.373 | 249.9 | 0.406 | 252.6 | 0.432 |
| 17255+0030 | RST | 5432 | 201.5 | 0.206 | 191.4 | 0.224 | 182.8 | 0.243 | 175.4 | 0.260 | 168.9 | 0.277 | 163.0 | 0.291 |
| 18018+0118 | BU | 1125 AB | 139.0 | 0.482 | 143.3 | 0.453 | 148.4 | 0.411 | 155.0 | 0.345 | 166.4 | 0.232 | 233.5 | 0.067 |
| 18043+4206 | COU | 1786 | 337.4 | 0.155 | 344.9 | 0.165 | 351.7 | 0.174 | 357.9 | 0.180 | 3.7 | 0.185 | 9.3 | 0.187 |
| 20210+4437 | A | 725 | 21.1 | 0.683 | 22.7 | 0.714 | 24.2 | 0.743 | 25.5 | 0.772 | 26.8 | 0.799 | 28.0 | 0.825 |
| 20330+4950 | MCA | 61 | 239.2 | 0.114 | 242.0 | 0.118 | 244.7 | 0.121 | 247.2 | 0.124 | 249.6 | 0.127 | 251.9 | 0.129 |
| 21047+0332 | SE | 3 BC | 126.1 | 0.596 | 128.4 | 0.622 | 130.5 | 0.647 | 132.5 | 0.672 | 134.4 | 0.698 | 136.1 | 0.723 |
| 21147-0050 | A | 883 AB | 306.2 | 0.161 | 300.6 | 0.160 | 294.8 | 0.156 | 288.5 | 0.149 | 281.6 | 0.140 | 273.5 | 0.128 |
| 22075+2538 | A | 308 | 310.9 | 0.183 | 312.7 | 0.180 | 314.6 | 0.175 | 316.7 | 0.169 | 318.8 | 0.163 | 321.2 | 0.156 |
| 22375+2356 | HU | 391 AB | 355.4 | 0.131 | 64.2 | 0.103 | 115.3 | 0.171 | 134.0 | 0.259 | 143.3 | 0.341 | 149.2 | 0.414 |
| 22383+4511 | CHR | 114 | 273.3 | 0.099 | 310.7 | 0.046 | 56.7 | 0.059 | 84.0 | 0.102 | 97.9 | 0.118 | 110.0 | 0.118 |
| 23019+4220 | WRH | 37 AB | 194.2 | 0.129 | 181.9 | 0.104 | 153.1 | 0.057 | 70.5 | 0.052 | 37.5 | 0.105 | 27.2 | 0.159 |

The pair has completed only a small fraction of its orbit, so any estimate of mass sum is premature.

15206+1523 = HU 1160. At a distance of about 30 pc, NLTT 39960 is the second-nearest pair among the new orbit doubles; it is also the high proper motion pair LHS 5294. It appears to consist of a pair of K2 dwarfs, whose mass sum would fall within the range predicted by this orbit ($1.2 \pm 0.5 M_\odot$).

15513-0305 = CHR 51. No magnitude difference has been published for this pair, but judging by the separation, observer's notes, and the known magnitude limit of the speckle technique, it may be estimated at perhaps 1 mag at most. The primary is of spectral type A3Vn; the secondary is probably mid- to late-A, and the predicted mass sum ($0.5 \pm 0.1 M_\odot$) is obviously an underestimate.

16085-1006 = BU 949. The orbit is both highly inclined and eccentric. Spectral types are F7V and roughly G5; the predicted mass sum ($2.4 \pm 0.6 M_\odot$) is reasonably plausible.

18018+0118 = BU 1125 AB. Also known as 68 Oph, one component of this pair is a variable star and possibly a spectroscopic binary. Phase coverage is still too incomplete for mass determination.

18043+4206 = COU 1786. Elemental errors are rather high, so the derived mass sum has a fairly large uncertainty

($3.5 \pm 1.4 M_\odot$). The spectral types are F0 and perhaps F5, with an expected mass sum of about $3 M_\odot$.

20210+4437 = A 725. Spectral types are K0 and perhaps K2 or a little later, in good agreement with the calculated mass sum of $1.5 \pm 0.5 M_\odot$.

20330+4950 = MCA 61. This pair was discovered by a photographic speckle technique in 1980 (McAlister et al. 1983) and has remained a close pair, although it is beginning to widen. Relative errors to both period and parallax are too large for mass determination.

21047+0332 = SE 3 BC. The secondary of the $\sim 3''$ visual pair STF 2749 (Struve 1837) was found to be double when Secchi (1860) split the B component in 1856. Lewis (1895) also split the A component in 1895, but this pair has been unseen except for three instances in the 1890s; these observations may actually have been of the Secchi pair instead. A wider D component was measured in 1920, but remains unconfirmed.

21147-0050 = A 883 AB. Star C (mag. 10.37, $21''$ separation) is thought to be probably physical, but the physical/optical nature of five other wide companions is unknown. The primary is of spectral type A1V, the secondary about A5; if it is indeed a physical companion, the C component would perhaps be of about F5 spectral type, based on the magnitude difference.

22075+2538 = A 308. Spectral types are about A2 and A5, yielding an estimated mass sum of 4.5 M_{\odot} . This orbit predicts a mass sum of 4.9 M_{\odot} —good agreement, albeit with an uncertainty of $\pm 4.1 M_{\odot}$!

22375+2356 = HU 391 AB. The A and B components are of spectral types K8 and \sim M0. A third component ($V = 12.4$, separation $\approx 6''$) shares a similar proper motion and is probably physical; its type is probably M2–M5.

22383+4511 = CHR 114. A G2III + A4V, but the predicted mass sum is in complete disagreement with these spectral types. The orbit is still uncertain, however, and the close separation could also have led to difficulties in deriving a good parallax.

23019+4220 = WRH 37 AB. Omicron And. The AB pair was first “officially” resolved by eyepiece interferometry in 1949 (Wilson 1950). However, that measure is so discrepant compared with other observations that the first actual resolution of this pair was probably that of McAlister & Hendry (1982), using a speckle camera at the KPNO 2.1 m in 1976. The primary is an 8y period, 40 mas pair discovered by speckle interferometry in 1975 (Blazit et al. 1977). SIMBAD also describes it as a β Lyr-type eclipsing binary. Finally, the B component is an SB2, with 33.01d period (Olečić & Cvetković 2006).

We extend our thanks to Hal McAlister, Dave Jurasevich, and the staffs of the CHARA Array and the Mount Wilson Institute, for their assistance and good cheer during these runs. Thanks also to “Captain” Kirk Palmer, for his unflinching humor and his devotion to the great Hooker telescope. Special accolades must go to technician *par excellence* Nils Turner, whose heroic efforts salvaged our 2006 run.

The USNO speckle interferometry program has been supported by the National Aeronautics and Space Administration under grant NNN06AD70I, issued through the Terrestrial Planet Finder Foundation Science program. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. Thanks are also extended to Ken Johnston and the U. S. Naval Observatory for their continued support of the Double Star Program.

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