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THE 2001 US NAVAL OBSERVATORY DOUBLE STAR CD-ROM. I. THE WASHINGTON DOUBLE STAR CATALOG

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ABSTRACT

The Washington Double Star Catalog (WDS), maintained by the US Naval Observatory, is the world's principal database of astrometric double and multiple star information. The WDS contains positions (J2000), discoverer designations, epochs, position angles, separations, magnitudes, spectral types, proper motions, and, when available, Durchmusterung numbers and notes for the components of 84,486 systems based on 563,326 means. The current version, available on-line, is updated nightly. This catalog is one of four USNO double star catalogs to be included on a new CD-ROM. A brief summary and statistical analysis of the contents of the catalog are presented.

Key words: binaries: general — binaries: visual — catalogs

1. INTRODUCTION AND GROWTH OF THE WDS

The Washington Double Star Catalog (WDS) is the successor to the Index Catalogue of Visual Double Stars, 1961.0 (IDS; Jeffers & van den Bos 1963). Three earlier double star catalogs in this century, those by Burnham (1906), Innes (1927), and Aitken (1932, ADS), each covered only a portion of the sky. Both the IDS and the WDS cover the entire sky, and the WDS is intended to contain all known visual double stars for which at least one differential measure has been published. The WDS is continually updated as published data become available. Prior to this, two major updates have been published (Worley & Douglass 1984, 1997). The WDS has seen numerous changes since the last major release of the catalog. The application of many techniques and considerable industry over the past few years has yielded unprecedented gains in both the number of systems and the number of measures, as indicated in Figure 1.

The growth since the 1996.0 edition is due to many sources; however, the most significant contributions are listed in Table 1. While many thousands of new systems have been added, many of these observing programs have resulted in a striking improvement in the number of observations per system, as shown in Figure 2, with a specific example in Figure 3. It is expected that with other large publications of data planned in the future (e.g., the Two Micron All Sky Survey [Skrutskie 2001] and the USNO CCD Astrograph Catalog [see, e.g., Zacharias et al. 2000], as well as further Tycho reduction [Fabricius et al. 2001]), the growth of the WDS will continue.

Primarily of historical interest, a list of the top 25 observers (based on the total number of measures and means) is presented in Table 2. In this table, numbers are based on the WDS reference code. Totals are provided for the number of means (usually, as published—a line of data in the WDS measurement database, each mean position often comes from several measures, usually increasing their accuracy). To the extent that it is known, multiple authors participating in a distinct group or project are counted together.

One of the largest listings in both Tables 1 and 2 is the Washington Fundamental Catalog (WFC; Wycoff & Mason 2001). These double star measures were extracted from the WFC, a collection of 144 astrographic and transit-circle catalogs covering a time base of over 100 years and most recently used in the computation of proper motions for the Tycho-2 project. While not intended as a double star reference, the utility of transit-circle and photographic measures were known early in the 20th century, and many of the doubles in the Astrographic Catalogue (Urban et al. 1998) were previously gleaned by Barton (1926) and others. However, there remained a plethora of double star measures in these catalogs, which have now been cross-referenced with the WDS to produce these totals.

Because of their historical importance and their continued use, a cross-reference file from the ADS (Aitken 1932) to the WDS discovery designation and abbreviated coordinates is provided on-line. In this file, all components associated with the ADS system are included even if they were not known at the time of the publication of the ADS. Duplicate and bogus systems included in the ADS have been excised.

Some detections are not included in the WDS. These include measures by long-baseline interferometry for which only visibilities and baselines are published (as opposed to a true ρ and θ). Also, various one-dimensional detection data (e.g., lunar occultation and some infrared speckle interferometry) are not included, as the measured separation is only a projection of the true separation. These data are available in the Third Catalog of Interferometric Measurements of Binary Stars (Hartkopf, McAlister, & Mason 2001b; hereafter the Speckle Catalog). The absence of ρ and θ information for the long-baseline interferometry data is perhaps most tragic, as these data cannot be readily combined with other "classical" double star data for a true combined solution.

2. NEGLECTED DOUBLES

A large number of systems in the WDS may be characterized as "neglected." These include unconfirmed binaries, as well as systems that have not been resolved for many years. The reasons for this neglect are varied: poor coordinates or large proper motion (so the systems are "lost"), erroneous magnitude or Δm estimates (so the systems are skipped over

[1] Retired.
[2] Deceased.

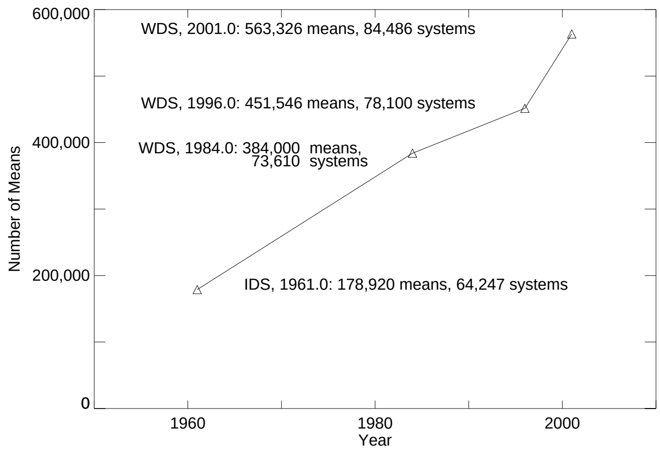

FIG. 1.—Growth in the number of means in the WDS since its inception in the early 1960s. The 1984.0 and 1996.0 editions of the WDS are indicated, and at the 2001.0 cutoff date for the CD-ROM production.

or misidentified), or true neglect (too many binaries and too few observers). While the veracity of some of these systems is certainly suspect, many (if not most) of these are bona fide double stars. Three sets of lists are provided in observing-list format. The first set was compiled using the following selection parameters:

1. Separation greater than 3″;
2. Δm (V band) less than 3 mag;
3. Both components brighter than 11th magnitude; and
4. One of three possible parameters meriting inclusion—
   a) Not observed in 20 years;
   b) Unconfirmed;
   c) Orbit system in the above parameter space, possibly useful for calibration.

A total of 6442 objects meet these criteria. Finding charts to these objects are available on-line. These are divided by declination into northern, equatorial, and southern lists. Two additional sets of lists are also available at the WDS Web site:[3] (1) 6632 systems compiled under the same criteria as above, but for separations under 3″, and (2) 45,768 systems not covered by the previous lists (but meeting criterion 4). This final list includes systems with large magni-

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

TABLE 1

LARGEST CONTRIBUTORS TO THE WDS, 2001.0

Group	Number of Means	Representative Paper	Note
Webb Society	4224	Argyle 2000	1
CHARA speckle	7122	Hartkopf et al. 2000	
USNO speckle	7140	Mason et al. 2000a	
Tycho-2	12770	Høg et al. 2000b	2
Hipparcos	13141	ESA 1997	
Washington Fundamental Catalog	36207	Wycoff & Mason 2001	

NOTES.—(1) Both current and many archival measures from the Webb Society have been added to the WDS. R. W. Argyle routinely provides Webb Society data in WDS format to facilitate timely folding of these data into the double star database. (2) See also Høg et al. 2000a. All stars are listed as separate entries in the Tycho-2 database. The double stars (both known and new) that these correspond to are described further in Mason et al. 2000b.

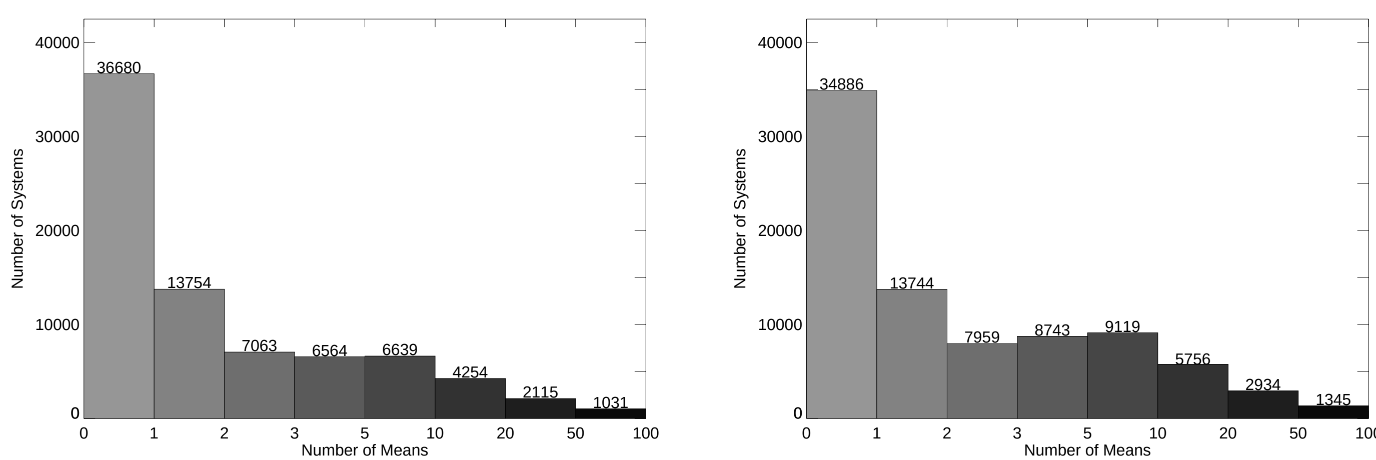

FIG. 2.—Number of means per system in the WDS. *Left*, histogram from late 1997 (the WDS 1996.0 with *Hipparcos* added, $N = 78{,}100$); *right*, the same information for the 2001 version of the WDS ($N = 84{,}486$). Note that while the total number of systems has increased by more than 1500, the number of systems with only one mean has dropped by more than 4500.

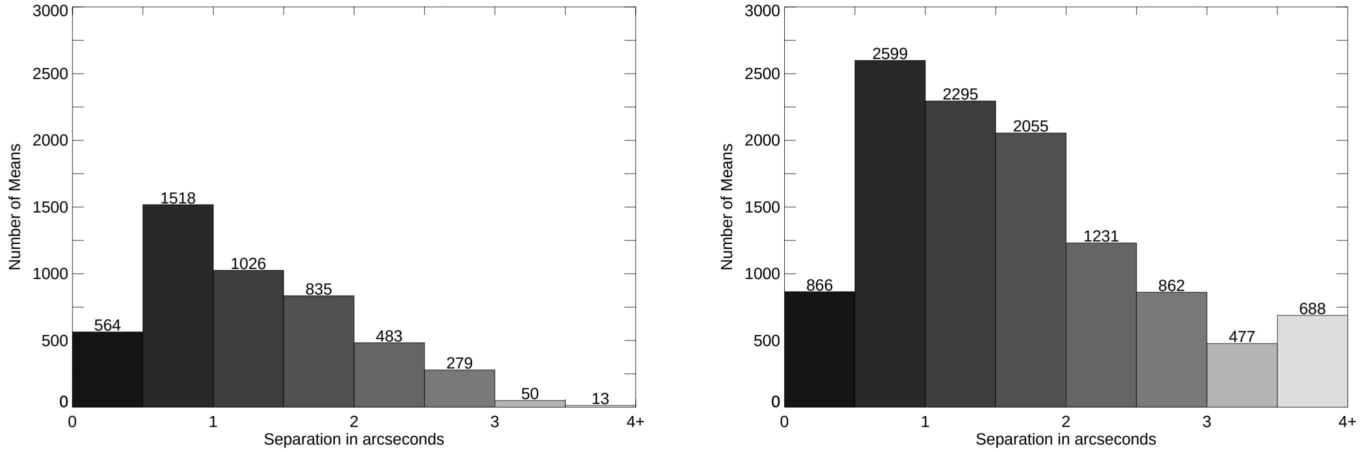

FIG. 3.—One source responsible for the increase in data is the prodigious publication of USNO speckle measures. The left panel illustrates a histogram of USNO speckle means (also late 1997) binned vs. separation ($N = 4768$). The right panel indicates the same information for the 2001 version of the WDS ($N = 11{,}073$).

tude differences, or fainter primary or secondary magnitudes, as well as systems whose magnitudes or separations are either unknown or unpublished. Custom-made observing lists tailored to specific observing needs may be prepared upon request (see § 4.2 below).

3. *HIPPARCOS* AND TYCHO-2

The current edition of the WDS contains the most recent observational data available and includes systems newly discovered by the *Hipparcos* mission (ESA 1997). While *Hipparcos* did not provide discovery designations, these are the primary system identifiers in visual double star astronomy. A cross-reference file of the 3406 systems first resolved by *Hipparcos* ("HDS" = *Hipparcos* double star) containing the abbreviated coordinates, as well as the HDS and HIP numbers, is available, as are cross-references of WDS entries that had *Hipparcos* problem solutions (i.e., the "G," "X," "O," and "V" double star solutions, as well as those that were suspected nonsingle). Systems with only one measure in the WDS that are *Hipparcos* problem stars (thus providing a "quasi confirmation") are indicated in the notes file.

The WDS also contains measures of 12,770 systems from the Tycho-2 Catalogue (Høg et al. 2000a, 2000b). These include 11,536 known systems, as well as 1234 newly determined ("TDS" = Tycho double star) systems from the

TABLE 2

WDS TOP 25 OBSERVERS

Rank	Observer	$N_{\rm means}$	$N_{\rm measures}$	Rank	Observer	$N_{\rm means}$	$N_{\rm measures}$
Ranked by $N_{\rm means}$				Ranked by $N_{\rm measures}$			
1	Washington Fundamental Catalog (WFC)	36447	58030	1	B	24373	73733
				2	WFC	36447	58030
2	W. H. van den Bos (B)	24373	73733	3	HEI	19959	54464
3	W. D. Heintz (HEI)	19959	54464	4	WOR	11838	37631
4	CHARA speckle (CHR)	19556	19809	5	RAB	6280	36850
5	G. Van Biesbroeck (VBS)	14635	35894	6	VBS	14635	35894
6	R. G. Aitken (A)	14377	26700	7	BU	12201	27530
7	R. A. Rossiter (RST)	13209	23813	8	A	14377	26700
8	*Hipparcos* satellite (HIP)	13147	13187	9	VOU	8211	26484
9	Tycho-2 Catalogue (TYC)	12770	12770	10......	COU	11228	25557
10......	Washington speckle (WSI)	12268	14590	11......	BAI	7758	24153
11......	S. W. Burnham (BU)	12201	27530	12......	RST	13209	23813
12......	C. E. Worley (WOR)	11838	37631	13......	DOO	6824	20940
13......	P. Couteau (COU)	11228	25557	14......	D	5452	20654
14......	USNO photographic	11077	11150	15......	CHR	19556	19809
15......	J. G. Voute (VOU)	8211	26484	16......	FIN	6327	15392
16......	P. Baize (BAI)	7758	24153	17......	WSI	12268	14590
17......	R. Jonckheere (J)	7739	12042	18......	MLR	6377	14550
18......	E. Doolittle (DOO)	6824	20940	19......	W. A. Doberck	4847	14182
19......	S. G. Barton (BRT)	6743	11974	20......	P. Fox	4854	13744
20......	P. Muller (MLR)	6377	14550	21......	HIP	13147	13187
21......	M. A. Pourteau	6357	6711	22......	TYC	12770	12770
22......	W. S. Finsen (FIN)	6327	15392	23......	J	7739	12042
23......	W. J. Luyten	6323	6326	24......	T. E. Espin	5196	12002
24......	W. Rabe (RAB)	6280	36850	25......	BRT	6743	11974
25......	E. Dembowski (D)	5452	20654				

Tycho-2 database. Also, notes have been added for 1130 systems of dubious veracity ($N < 3$) having a single-star solution in Tycho-2. Some of these are being reconsidered as further processing of the Tycho data continues (Fabricius et al. 2001). All these files are available on-line at the WDS site.

4. OTHER CHANGES IN THE WDS

4.1. *Changes in the Reference File*

The reference file appears in a different format than previously available. In the past, three characters would specify to whom the reference belonged, with a two-digit number indicating the specific reference. In the case of some observers, this was proving inadequate. The problem was exacerbated by the fact that the WDS, the Fifth Catalog of Orbits of Visual Binary Stars (Hartkopf, Mason, & Worley 2001a, hereafter the Orbit Catalog), the Speckle Catalog, and the Photometric Magnitude Difference Catalog (Worley, Mason, & Wycoff 2001, hereafter the Δm Catalog) all used different reference codes. A new reference file is therefore provided that gives the new code, as well as the WDS reference code, followed by the reference. This is expected to change over time as the WDS is reformatted and the old WDS catalog code is replaced. The additional discoverer codes are included within this file. The reference file is also available on-line at the main WDS site.

4.2. *Changes in the Data-Request Software*

The data-request software has been rewritten and the output is in a new format that is (hopefully) more user friendly. Also, the software now searches the Δm Catalog and the Orbit Catalog in addition to the WDS. Over time we will be adding other features in a data-request package.

In addition, we now also provide custom-made observing lists. If the user provides limitations as to right ascension, declination, separation, magnitudes, number of observations, and date of last observation, it is possible to prepare observing lists. Both data requests and observing-list requests are available on-line.[4]

4.3. *The Δm Catalog*

New to the WDS is an additional indicator in columns 100–102. This " D " note code indicates that the system has additional Δm information tabulated in the Δm Catalog (in addition to those determined during astrometric measures). These results will eventually be incorporated in a weighted scheme for the magnitude listings of the WDS data line.

4.4. *Discovery Designations Added*

The coordinates provided for entries in the WDS are neither unique nor constant and are therefore unsuitable to identify systems. Following the assignment of HDS designations to systems first resolved by the *Hipparcos* satellite, an effort was made to assign unique discovery codes to all other systems in the WDS. In some cases, two different systems can have the same discovery code and number, but different components. Therefore, to uniquely identify a system it is necessary to include the component field. Eight hundred twenty-two systems have had their discovery number assigned by the USNO in this manner and are identified in the notes file.

5. SYSTEMS REMOVED

Forty-seven pairs of systems have been identified as being equivalent. Many of these were first identified by Fabricius et al. (2001) while working on the Tycho-2 double star reduction project. Notes to the systems that are retained also indicate the alternate designations. These and other errata are provided in an error correction file that is available on-line. Many other systems remain to investigate as potential identical systems, as noted by Morlet, Salaman, & Gili (2000), Fabricius & Makarov (2000), and others.

5.1. *Future of Designations*

On 2000 August 11, during the 24th General Assembly of the International Astronomical Union, a multicommission meeting (MCM) on stellar designations was held. The purpose of this meeting was to develop a simple, unambiguous, flexible, and computer-friendly designation scheme for all stellar companions (including planets). Members from nine supporting commissions participated, and as a result, a C-type IAU resolution was drafted and adopted by Commissions 26 and 42 and later ratified by Commissions 5 and 8 + 24 at their respective business meetings. Subsequent to the MCM on October 24, Commission 45 Scientifc Organizing Committee members unanimously supported the resolution. Further details are available online.[5]

6. SINGLE STARS

For observations of double stars it is often necessary and beneficial to observe single stars. These can serve as an idealized point-source function to determine the behavior of various elements in the optical chain or characterize various reduction algorithms, or be used to generate artificial double stars or other more complicated morphologies by use of calcite crystals, slit masks, aperture masks, etc.

Unfortunately, finding a good list of these calibrator sources is more difficult than it sounds. Generally speaking, the more that stars are studied, the higher their multiplicity fraction. Erroneously labeled " single stars " can render vital calibration data useless through the discovery of a previously unknown companion or the slight modification of the point-source function by an unresolved component.

The basic data for this list come from the Speckle Catalog, which tabulates null detections from various duplicity surveys in addition to double star measures obtained by speckle interferometry and other high-resolution techniques. Stars from the Bright Star Catalogue (Hoffleit & Warren 1991)[6] are checked against the WDS, the Speckle Catalog, and the *Hipparcos* Catalogue (ESA 1997) and only considered to be " single " stars if all the following criteria are met:

1. The stars show no indication of duplicity in any of the three catalogs.
2. The stars have tabulated null detections in the Speckle Catalog, at least one of which was obtained with a telescope of 2 m or greater aperture.

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[4] See http://ad.usno.navy.mil/ad/wds/wds_request.html.

[5] For the home page of the MCM, see http://ad.usno.navy.mil/ad/wds/iaumcm.html; for the WMC (Washington Multiplicity Catalog) nomenclature scheme, see http://ad.usno.navy.mil/ad/wds/newwds.html; and for the text of the approved resolution, see http://ad.usno.navy.mil/ad/wds/resolution.txt.

[6] See http://cdsweb.u-strasbg.fr/cgi-bin/Cat?V/50.

TABLE 3

WDS SAMPLE

WDS Identifier	Discovr	Comp	EPOCH Frst	EPOCH Last	#	THETA FST	THETA LST	RHO First	RHO Last	Magnitudes Pri	Magnitudes Sec	Spectral Type	PROP. MOT RA"	PROP. MOT DEC"	DM Desig	Note
00000+7530	A 1248		1904	1982	5	246	235	0.8	0.6	10.5	11.5				+74 1056	
00000+4004	ES 2543		1931	1 4.8		4.8	11.0	12.0								
00002+0146	WEI 45		1879	1999	18	89	82	1.8	1.9	10.09	10.52	G0	+039	-020	+00 5079	ps
00002-2519	COO 273		1910	1991	7	10	11	9.0	8.5	10.13	10.20	G	+006	+005	-2616866	Np
00003+1642	HJ 318		1820	1999	6	270	62	12.0	26.5							N D
00004+0830	BU 732	AB	1878	1928	7	152	155	6.1	6.2	9.2	11.4	K0	-005	-044	+07 5114	pD
00004+0830	BU 732	AC	1913	1991	2	143	142	152.5	153.0	10.05	8.47		+006	-004	+07 5115	pD
00011+6935	STT 253	AB	1875	1995	16	353	355	100.5	100.8	7.57	8.03	B9	+009	-018	+68 1418	Na
00011+6935	STT 253	AC	1983	1991	2	191	191	185.7	188.1	7.56	8.87					
00014+3937	HLD 60		1881	1998	99	124	174	0.6	1.0	9.09	9.77	K0V K1V	-026	-037	+38 5112	pOD

3. The stars have no *Hipparcos* double star solutions (C, G, X, V, or O codes in field H59 of the main catalog) and no S (" suspected nonsingle ") code in field H61.

The final all-sky list containing 1170 systems fulfilling these criteria is available on-line at the main WDS site. In the future, it is planned to update this list to include systems that would be unresolved by optical interferometry.

7. THE CATALOG

Measures in the Washington Double Star Catalog have been collected, collated, and maintained since the early 1960s, when the original IDS (Jeffers & van den Bos 1963) was transferred from Lick Observatory to the US Naval Observatory. A sample portion of the current catalog is shown in Table 3. Presented in order are the WDS J2000 coordinates, the discovery and component designation, the first and last measured epoch, the number of means, the first and last measured position angle (θ) in degrees, the first and last measured separation (ρ) in arcseconds, the magnitudes of the primary and secondary, the spectral type of one or both components (if known), proper motion in right ascension and declination (milliarcseconds per year), the Durchmusterung (DM) number,[7] and a notes column. It should be noted that the WDS is not a photometric or spectral type catalog, and while the catalogers strive to provide the most correct values for these parameters, they should not be considered definitive. Some characters in the notes column indicate specific entries in another file (i.e., an " N " indicates an entry in the notes file) or catalog (an " O " for the Orbit Catalog, and a " D " for the Δm Catalog) or are referenced in the format file. The full catalog (10.1 Mbyte) is available on-line, as are format, note, reference, and other ancillary files. The WDS 2001.0 is also available on a CD-ROM of USNO double star catalogs. Copies of this CD-ROM can be obtained from the authors.

[7] The DM number of the object in the system used by the Henry Draper Catalogue: Bonn from $+89°$ to $-22°$ inclusive, Córdoba from $-23°$ to $-51°$ inclusive, Cape Photographic from $-52°$ to $-89°$ inclusive.

8. CONCLUSION

Addition of the Δm information, as well as other more significant changes to the WDS database, are currently under consideration. The input from regular users of the database and other interested parties is greatly appreciated in our efforts to make the WDS as helpful and user-friendly as possible. Please provide comments on the format of the WDS, missed references, or any other items of interest to you on our comment form.[8] Information is being added to the database on a continuing basis, and this edition of the WDS will also be updated regularly.

If the WDS and associated databases were helpful for your research work, the following acknowledgment would be appreciated:

> This research has made use of the Washington Double Star Catalog, maintained at the US Naval Observatory.

A notification of references to relevant papers is appreciated.

We are in debt to Geoff Douglass for his work on the WDS database and his leadership in the speckle program at the USNO. The Washington Double Star Catalogs and USNO speckle program were conceived and nurtured by Charles Worley. Providing data in WDS format (or at least electronic format) has allowed the WDS to grow significantly. We would here like to acknowledge the contributions of Bob Argyle, Wulff Heintz, Elliott Horch, Josefina Ling, Francisco Manuel Rica Romero, Walt Sanders, and Jan Weis.

[8] See http://ad.usno.navy.mil/ad/wds/wds_comment.html.

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