

Classical Observations of Visual Binary and Multiple Stars

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Abstract. Changes in the double star database are highlighted, describing various methods of observation (both historically and those of the past few years) and their effectiveness in different regimes of separation space. The various niches for wide- and narrow-field work as they apply to double and multiple stars are examined and the different types of information which each can provide are described. Despite the significant growth of the double star database, much can still be done, such as finding lost pairs, filling in missing parameters so that observing programs can select all stars appropriate to their capabilities, or providing at least gross kinematic descriptions. After more than 20 years of successful work, speckle interferometry and conventional CCD astrometry have replaced filar micrometry and photography as preferred classical techniques. Indeed, most work in filar micrometry is now being done by amateurs. Work on pairs described as neglected in the last major WDS data release (2001) is given as a specific example. Finally, the continued need to publish data in classical double star parameters is also discussed.

Keywords. binaries (including multiple): general, binaries: visual, catalogs

1. Growth of the WDS

The *Washington Double Star Catalog* (hereafter, WDS) has had significant growth in the past decade, both in the total number of mean positions (measures) and the number of systems. Due to the small number of measures per system, establishing which are true binaries (physical systems) is possible only for a subset of pairs. While the mean number of measures per system is 7.1, the median is only 3. In Figure 1 the growth of the WDS is plotted at top. The solid line and filled circles indicate the number of mean positions (left axis) for the major releases of the WDS, while the dashed line and open circles indicates the number of systems (right axis). At bottom is a histogram indicating the number of means per system. While the average number of means per system has climbed due to matching with various astrometric catalogs, determining the kinematic properties for the majority of systems remains an elusive task. Of all the pairs currently in the catalog, 1522 have orbits of varying quality, 354 have common parallax, and an unknown number have common proper motion, a known physicality rate of about 2%. About 1% are certainly optical: 1163 have rectilinear solutions computed and 174 have mutually exclusive parallax, leaving the vast majority (~97%) unknown.

Table 1 gives a few statistics on data added to the WDS database in time for its various releases. For example, the line labelled “1984” describes all data included in the WDS database at the time of the first WDS release in 1984, “1996” the data added between 1984 and 1996, and so on. Measures added since the 2001 release have been divided into two categories: “old” measures (data published before 2001 but not added to the WDS until recently) and “new” measures (data published since 2001). As this breakdown illustrates, a considerable fraction of the additions to the WDS in the 5.5 years

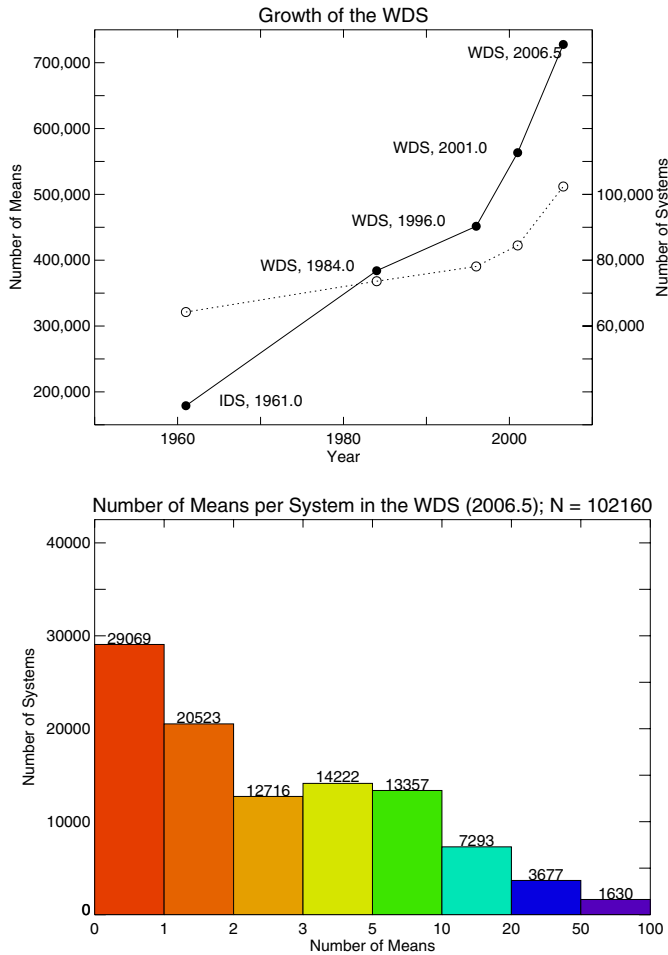


Figure 1. *Top:* Growth of the WDS. *Bottom:* Histogram of means per system.

since the last major release have come from data mining of astrometric catalogs. Improving WDS coordinates from arcminute to arcsecond precision allowed the matching of many historical astrometric catalogs against the WDS to add measures for these (mostly wide) pairs. While this can help considerably for wide pairs and aid in determining if they have the same proper motion, these data are generally not applicable to orbit pairs which require long-focus, and in some cases high angular resolution techniques. In Figure 2 is shown the normalized additions by various techniques to the major releases of the WDS. Micrometry has seen a steady decline. Wide-angle work made major contributions in the past few years, primarily from the AC and 2MASS (Wycoff *et al.* 2006) catalogs. High-resolution observations are primarily due to speckle interferometry, but also includes adaptive optics and similar techniques. Space-based measures include results from both the high-precision HST fine guidance sensors as well as the all-sky Hipparcos and Tycho satellite (hence the large contribution by this technique to the 2001 release).

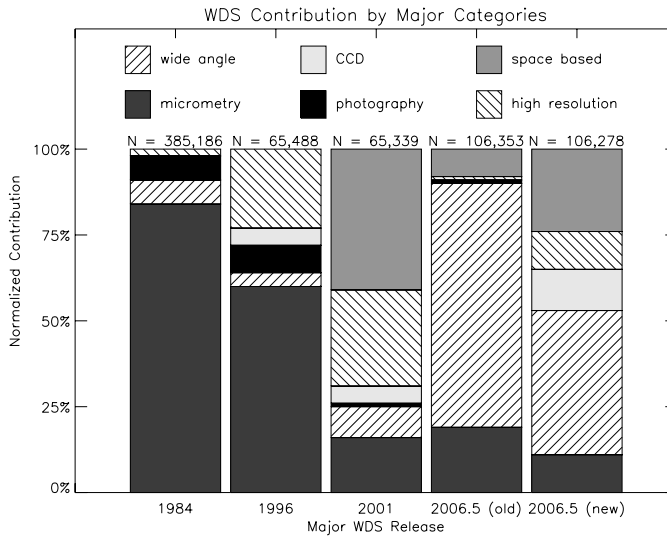


Figure 2. Sources of WDS data.

Table 1. Statistics of WDS additions

WDS Release	N means added	Mean ρ (")	Median ρ (")	% < 1"	N < 0".1	N < 0".01
1984	385,186	8.01	2.30	29.3	943 (0.2%)	0
1996	65,488	12.62	1.68	41.1	1670 (2.6%)	0
2001	65,339	10.71	1.87	32.2	1230 (2.0%)	255
2006.5 (old)	106,353	33.12	14.42	2.0	73 (\ll 1%)	0
2006.5 (new)	106,278	19.92	7.62	16.8	301 (0.3%)	34

2. Physical Systems

Visual orbits can be of varying quality, with some that are well-observed and well-defined to others that are only marginally defined. However, even a curve indicating Keplerian motion with scant coverage can yield a solution where the important quantity $3 \log(a) - 2 \log(P)$ is often not grossly erroneous. Pairs with poor quality orbits or physical binaries with no orbits at all need continued vigilance at the appropriate observing cadence while others need observations with specific techniques and/or telescopes. Orbits of two well-observed pairs are displayed with their data in Figure 3. In these, and other figures like them, the calculated orbit of the secondary relative to the primary is indicated by the solid ellipse. Measures by different techniques (e.g., plus signs for micrometry, solid circles for speckle interferometry) are connected to their predicted positions along the orbit by solid $O - C$ lines. The scale in arcseconds is indicated on the axes and the direction of motion at the lower right. The broken line indicates the line of nodes. The pair at left, 70 Ophiuchi, is the most frequently observed binary in the WDS and has an orbital period of ~ 88 years with data as far back as 1779, so is very well characterized. The plotted orbit is by Pourbaix (2000). At right is the relative orbit of the wider pair of ϵ Hydrae. While also well-characterized over the observed portion of its orbit, only about 20% of the orbit has been observed, despite having data since 1825. The nearly 1000-yr period orbit shown in the figure is by Heintz (1996). The closer pair in this system, with an orbital period of ~ 15 years, is extremely well characterized, as well.

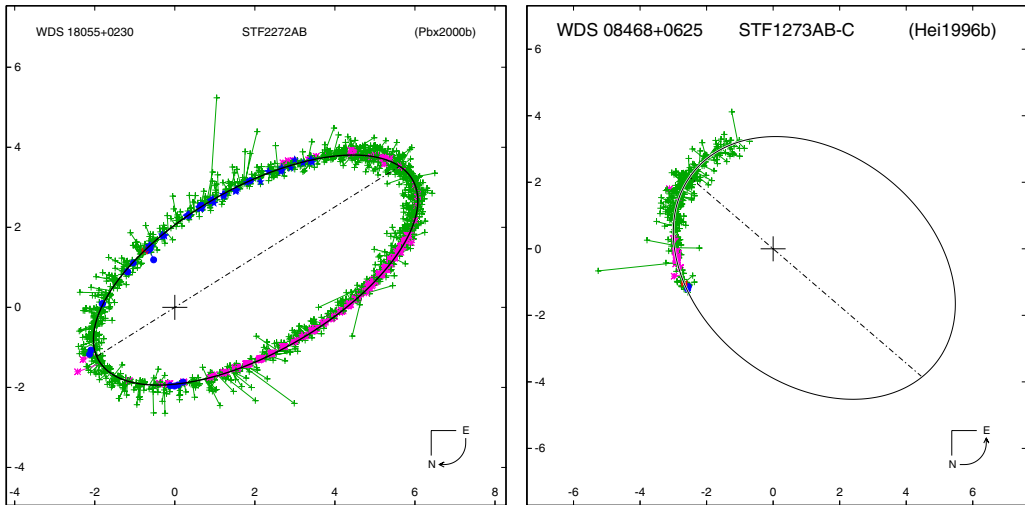


Figure 3. *Left:* Relative orbit of 70 Ophiuchi. *Right* Relative orbit of the wider pair of ϵ Hydrae.

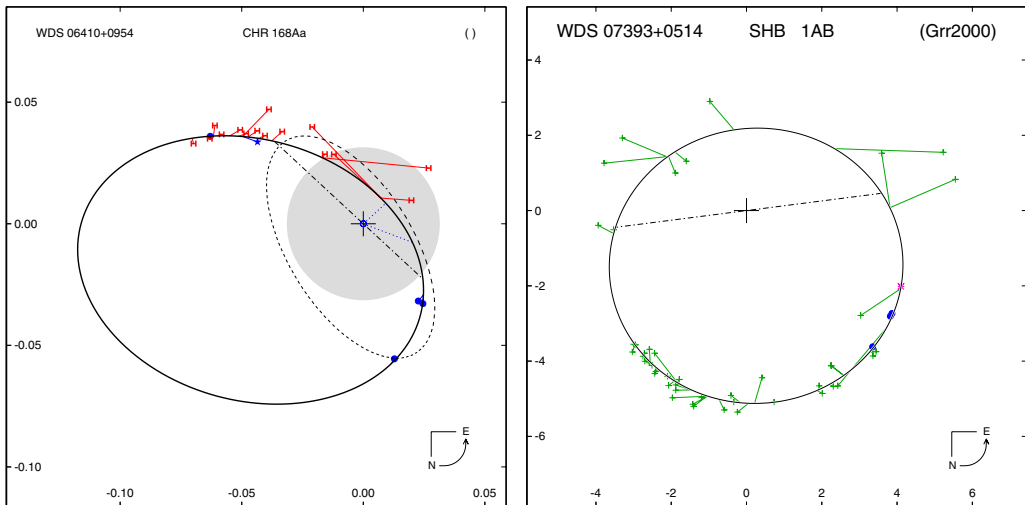


Figure 4. *Left:* Relative orbit of 15 Monocerotis. *Right* Relative orbit of Procyon.

While ϵ Hydrae just needs more time to complete its orbit, the pairs in Figure 4 need more specialized data acquisition. The massive and very important speckle/spectroscopic O star binary 15 Monocerotis is at left. A challenging target, this pair has only been split by speckle interferometry with a 4-m class telescope (open circle and \star), Hubble Space Telescope fine guidance sensors (HST-FGS; **H**), or long-baseline optical interferometry (filled circle). The resolution limit of a 4-m telescope is indicated by the lightly-shaded circle at the origin. This orbit is based on many unpublished observations. At right is plotted the relative orbit of Procyon by Girard *et al.* (2001). Although the secondary has been known for well over a century, the large Δm has continued to make resolving this pair quite challenging — no astronomer living has split this pair with the naked eye!

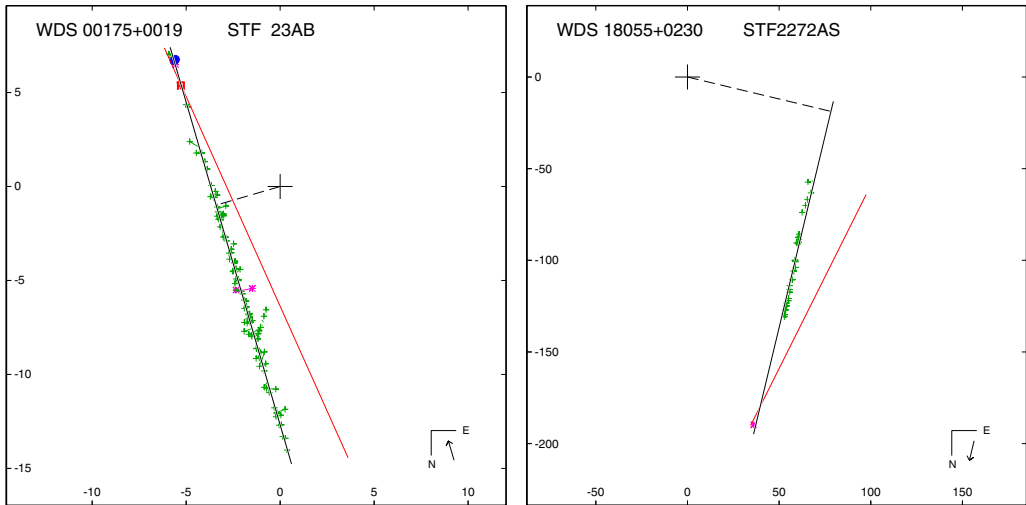


Figure 5. *Left:* This is the linear fit to the double STF 23. *Right* Linear fit to one of the wide components of 70 Ophiuchus.

3. Optical Systems

Even optical systems can be of value. While continuing to catalog these pairs can prevent their “re-discovery,” the motion of one relative to the other due to differential proper motion can aid in a variety of applications. Due to the often longer timebase and frequently larger number of observations, the relative proper motion of optical double stars has been found to be more accurate than either high precision short- or long-period classical proper motion determination techniques (Kaplan & Snell 2001) and submotions to the linear fits can indicate the presence of closer pairs. Finally, these pairs can be exceptional calibrators of rotation and plate scale. In Figure 5 are examples of these two. At left is the linear fit to the double STF 23. Seen almost due North by F.G.W. Struve in 1825 (1837), the companion has moved southwest since then. The best relative proper motion here indicated is from Tycho-2 and deviates significantly from the historical measures. At right submotion seen in a more distant optical component can indicate a closer physical pair, in this case the known binary 70 Ophiuchus (see Figure 3).

4. Work Still to be Done

Filling in missing parameters in catalogs such as the WDS is not mere “stamp collecting.” When all these parameters are complete — position, relative position, magnitude, proper motion, etc. — observing programs may be more efficient at observing stars appropriate to their capabilities, so that at least approximate kinematic descriptions can be assigned to them.

A large number of systems in the WDS may be characterized as “neglected.” These include unconfirmed binaries as well as systems which 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 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. Unconfirmed pairs need to be verified as real and if their

Table 2. Neglected Doubles by Catalog Release.

Release	easy	easy but close	unknown
2001	6307	6630	58,842
2006.5	946	4376	39,585

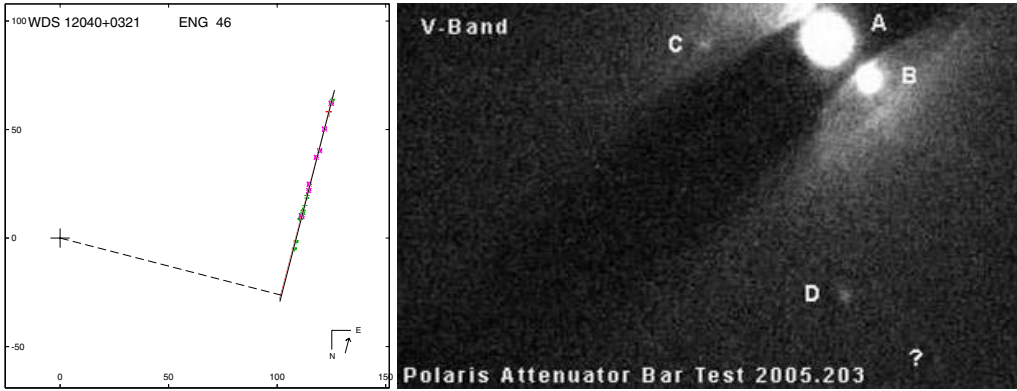


Figure 6. *Left:* This is the linear fit to the double ENG 46. *Right* CCD frame of Polaris (image courtesy of Jim Daley).

motion cannot be characterized, at least the appropriate re-observation cadence needs to be determined.

In Table 2, “easy” pairs are defined as those wider than $3''$, with a Δm smaller than 3 magnitudes and both components brighter than 11th magnitude. Those characterized as “easy but close” have the same two latter discriminators but are closer than $3''$. Any not matching these two sets, including pairs with one or more completely unknown characteristics, are in the largest, and most challenging, third set. Note that while the number of pairs (which start off as neglected as they are unconfirmed) has significantly increased the number of neglected pairs in all categories has decreased. The five largest contributors, by number in the observation of these pairs is:

- (a) USNO matching of 2MASS (39,580; Wycoff *et al.* 2006)
- (b) Tycho-2, primarily the TDSC (8071; Fabricius *et al.* 2002)
- (c) Washington Speckle Interferometry (6233; most recently Mason *et al.* 2006)
- (d) T. Tobal (4256; <http://ad.usno.navy.mil/wds/wdstext.html#unpublished>)
- (e) D. Arnold (2509; most recently Arnold 2006)

As enumerated above, much of the work on neglected pairs has been done by amateurs. While quality control can be a concern, qualifying who is and who is not an amateur is at least as difficult a task. The work produced by these “financially uncompensated astronomers” has made and continues to make significant contributions. Examples of this are given in Figure 6. At left, historical measures of the AC, the AGK3, and others as well as more recent measures from 2MASS and Dave Arnold (2006) have allowed for this precise differential proper motion to be determined. At right, the C and D components of Polaris were observed by S.W. Burnham (1894) on the Lick 36-in at the close of the 19th Century and not split again until 2005 when Jim Daley (2006) recovered them. Many other large Δm systems still remain neglected.

Table 3. Major New Sources of Data.

Data Source	Number of Observations	Approximate Date
Hipparcos	19,146	Early 1990s
Tycho	40,277	Early 1990s
2MASS	42,078	Late 1990s
UCAC3	50,000+	Late 1990s

Other work could possibly be more beneficial to other areas of binary star astronomy. For example, third light components are detected in many eclipsing binary solutions. These can also show up as stationary contributors to the spectrograms of close binaries. A comprehensive listing of available information about these systems, such as the date of detection, an upper limit on ρ , and an approximate Δm , would be beneficial. It is possible that the magnitude difference may be more valuable than the separation for these objects.

5. Problems & Solutions

While specific large projects have made significant number of observations, and have found many pairs that were listed more than once, they are over a limited timebase. Although this can aid in the observation of wide pairs and in determining which ones have the same proper motion, the programs themselves are not appropriate for orbital solutions. They may be adequate for simple kinematics, determining common proper motion pairs, and finding missing doubles, but they are not adequate for complex dynamics. Characterizing these orbit pairs requires perseverance over an extended period of time.

These data sources have indicated systems appropriate for follow-up observation. For example, the resolution capability of Hipparcos is of the same order of magnitude as ground-based speckle interferometry and follow-up data for the fast-moving Hipparcos discoveries have produced numerous short-period orbits (see Balega *et al.* 2005, 2006). Continued observations of these pairs will keep ground based astronomers busy for many years (Horch *et al.* 2004, Mason *et al.* 2001).

6. LBOI

Of all techniques for resolved pairs the one with the greatest potential is long baseline optical interferometry (LBOI) which can observe many of the most interesting systems and have very meaningful synergy as the pairs resolved with it are preferentially spectroscopic binaries and can be eclipsing pairs as well.

However, rather than the more conventional separation (ρ) and position angle (θ), data are often presented in terms of the less intuitive baselines (B) and visibilities (V or V^2). The advantage of getting greater comprehension among colleagues and (perhaps as important), funding officials is very important. Visualizing ρ and θ on the sky can be easier than the more abstract B and V^2 . While many LBOI targets are new resolutions, there exist many appropriate known systems as well. While the published data obtained using different techniques are of admittedly lower accuracy and/or precision than obtainable by LBOI, they may still provide other benefits. Probably the best example of this would be the pair known as “The Interferometrist’s Friend,” Capella.

First resolved in 1919 with the 20-foot beam inteferometer on Mount Wilson (Anderson 1920), Capella had completed almost 3 full revolutions by the time of Merrill’s orbit (1922). It was not recovered again for nearly fifty years and by the time of the orbit

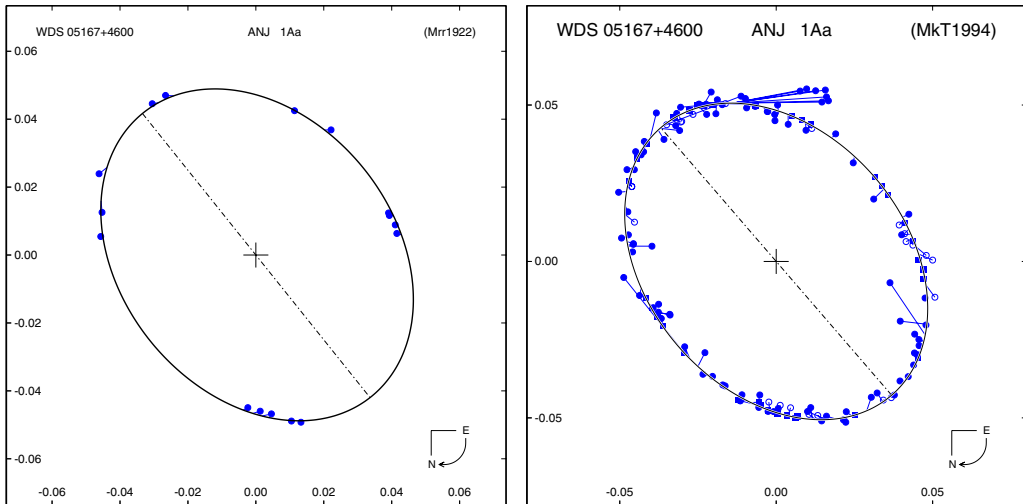


Figure 7. *Left:* Data and Merrill's 1922 orbit of Capella. *Right:* Data and the 1994 orbit from the Mark III of Capella.

update of McAlister (1981), Capella had gone around over 217 times. While the accuracy and precision of speckle interferometry were important, the enormous lever arm afforded by the earlier astrometry allowed the period to be determined with far greater precision. Nearly 50 additional revolutions occurred before data from the Mark III, also on Mt. Wilson, were used to further refine the period (Hummel *et al.* 1994). This, coupled with the superior data from LBOI has given this orbit staying power.

If the interferometer has more than two elements and they are not in a line it should be possible to express parameters in the conventional ρ - θ space (see, for example, the NPOI measures of α Leo; Hummel *et al.* 2001). If the $P \gg 1$ day the rotation of the Earth can help fill out the uv-plane (e.g., the SUSI measures of β Cen; Davis *et al.* 2005) and also allows observers to express parameters in ρ - θ space. The difficulty may be in rapid moving systems when only two-element interferometers are used (e.g., the PTI orbits of Boden *et al.* 1999). Are we in a regime where the B - V^2 are only an intermediate step and we'll eventually end up back in a ρ - θ way of thinking, or do we need a new paradigm and new orbit calculation tools? Catalogers, observers and orbit computers need to know, and the observables which should be cataloged remains an elusive question. Heed should be given to words of Ejnar Hertzsprung (Lippincott 1962), 45 years ago:

The debt to our ancestors for the observations they made to our benefit, we can pay only by doing the same for our ancestors.

As we use observations made in the past, we need to ensure that the observations made today are not just for today, but speak to the future.

Acknowledgements

The author is supported by NASA under JPL task order # NMO710776. This support is gratefully acknowledged.

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Discussion

TOM CORBIN: Considering the large astrometric catalogs that are coming out and will come out (in particular Gaia), will the WDS become a catalog that is mostly stars where a common proper motion is all that is known about the pairs?

MASON: It may be appropriate to have an addition “faint stars annex” for many new Gaia common proper motion pairs. The amount of data it generates will present challenges.

RAGHAVAN: Here are some WDS stats — optical versus physical — for an FGK sample within 25pc. Some 204 out of 455 primaries have WDS entries. These 204 primaries have 448 entries, and of the 448 entries:

- 271 (60%) are optical pairs
- 125 (28%) are physical pairs (i.e., have orbits or are clearly CPM)
- 52 (12%) are undetermined as of now

Also, contamination from field stars is expected to be higher for nearby stars and hence my sample will have a higher percentage of optical alignments.