On Line Double Star Resources at the U.S. Naval Observatory

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Abstract: Double Star Resources available through the world wide web from the U.S. Naval Observatory are described in this article.

For over one hundred years the astronomers at the U.S. Naval Observatory (USNO) have made observations, calculated orbits, and maintained catalogs related to double stars. These have led to an assortment of data products and other resources which we maintain and keep online. These resources will be enumerated below, although, exploring the website links on your own is probably the best way to learn what is available.

1. Washington Double Star (WDS)

Catalog
http://ad.usno.navy.mil/wds/wds.html

History
The root catalog at the USNO, the WDS was established by Charles Worley in the early 1960s when Lick Observatory double star astronomers were retiring. Worley transferred their Index Catalogue of Double Stars (IDS) and drawers of measures to Washington. The IDS was created from a merger of Aitken's Double Star (ADS) catalog and the Southern Double Star (SDS) Catalogue of Innes and van den Bos. The ADS was the successor to Burnham's Double Star (BDS) Catalogue which was published in 1906. Thus, next year marks the centennial of the publication of the great-grand-catalog of the WDS!

Website
The WDS web site contains both the WDS summary catalog and lists of references and notes associated with it. Measures and systems are constantly being added to the WDS database [figure 1], and programs are run every night to build a new summary catalog. Also on the web site are brief overviews of the data and some statistics associated with them.

Cross references to various other catalogs (ADS and BDS number) are provided as well as explanations when entries in those earlier catalogs have been omitted from the WDS. Various people and groups who, for one reason or another, did not publish their data have electronic listings of their data here. In 2001, lists of "neglected doubles" were prepared for the USNO Double Star CD. These have provided fodder both for our observing programs as well as others. Finder charts are provided for a sample of the arguably easiest resolvable of these as well. The Hipparcos and Tychos

Figure 1: Growth of the Washington Double Star Catalog.
mission was a major source of data for the WDS; lists of doubles discovered by those missions and cross-references to the WDS are also provided. Lists of changes since the WDS, 2001.0 (CD version) are provided (for example, removal of may duplicate discovery designations added by the IDS), lists of well-examined, suspected single stars, and other ancillary files.

**Catalog**

The WDS catalog, modeled on the IDS style, provides summary information for each measured pair known. An example is given below, along with an explanation of each field. [figure 2]

11182+3132 10 digit approximate position (J2000) of the system primary star. 11 hours, 18.2 minutes RA, +31 degrees, 32 minutes declination. These serve as the shorthand coordinates for all pairs in the WDS.

STF1523AB Discovery and component designation. This is #1523 in the lists of F.G. W. Struve. Since this is designated AB, it indicates that these are (probably) the two brightest stars in a multiple star system. If the "AB" were not provided it would be a simple double star system. This one has additional components.

1780 Date (year) of first observation.

2004 Date (year) of most recent observation.

1530 The number of mean published positions for the pair. Fewer than a dozen systems in the WDS have this many.

144 position angle at "first" date.

245 position angle at "last" date.

3.5 separation in seconds of arc at "first" date.

1.7 separation in seconds of arc at "last" date.

4.33 V magnitude of the primary.

4.80 V magnitude of the secondary.

**F9V G9V** Spectral types of the primary and secondary. It is rare to have both. Since the WDS is not a catalog of spectral types, this is ancillary data. Many systems have no spectral type information at all.

-454-591 Proper motion in RA and Dec of the primary.

-454-591 Proper motion in RA and Dec of the secondary. Only about 20% of WDS systems have secondaries with a proper motion listed.

+32 2132 Cross-reference for the pair. In this case, BD+32 2132.

NOD Notes columns indicating (in this case) that the pair has a more extensive note in the WDS notes file, an Orbit in the 6th Orbit Catalog, and an entry in the Delta-M Catalog.

111811.2 +313150. Precise position. 11 hours, 18 minutes, 11.2 seconds RA, +31 degrees, 31 minutes, 50. seconds Dec. Unlike the WDS coordinate this lists the precise position of the primary of this subsystem. For example, a CD pair would have the same WDS coordinate but a different precise coordinate. Nearly 95% of WDS pairs have these very precise positions and more are being constantly added.

**Future**

The WDS will continue to grow, though there are no anticipated format changes in the future. The biggest task on the horizon will be the matching of the WDS with the UCAC3 when it is released and a new "neglected double" list will be prepared soon.

2. Sixth Catalog of Orbits of Visual Binary Stars (ORB6)


**History**

The first two Catalogs were published by the great South African visual interferometrist William S. Finsen in 1934 and 1938. In 1963, Charles Worley published a visual orbit catalog and then in 1970 he collaborated with Finsen to produce the 3rd Catalog. In 1983 Charles teamed with Wulff Heintz (the "Swarthmore Orbit Machine") and produced the 4th Catalog. Charles continued working on orbits and had made additions and regrading of orbits, the bulk of which was incomplete at the time of his death in 1997. In 2001, Hartkopf and Mason took Worley's work and produced the Fifth Catalog which appeared on the Double Star CD. Before very long, the online version diverged from this and was dubbed the Sixth Catalog.

**Website**

One of the features of earlier versions of the visual orbit catalogs was a single number grade (1-5) indicating, very generally, the quality of the orbit. Much of the effort in producing the Fifth Catalog was a labori-
ous effort to generate algorithms and rules to make the grading more objective. These are all explained in great detail. Also a link to systems deemed sufficient for gross calibration purposes is provided (http://ad.usno.navy.mil/wds/orb6/orb6c.html).

Catalog

For each of the 1832 orbits of 1735 systems, ORB6 provides epoch 2000 precise coordinates, WDS coordinate and discovery designation as well as a variety of cross references (ADS, HIP and HD number), and the magnitudes of both components. For the actual orbits we provide the seven classical Campbell elements in their usual units and errors to these values (when provided), the orbital grade (again, 1-5, with 1 = "definitive" and 5 = "indeterminate"), notes to the system, the reference for the orbit, an ephemeris providing predicted positions for the next five years, and a figure providing a visual representation of the orbit overplotted with all WDS data. Systems in the WDS which have entries in ORB6 have an "O" or "C" in the note area of the WDS. There are also pairs in ORB6 which are not in the WDS. These, for example, include orbits calculated from their submotions (astrometric wobble), or baseline-only solutions from long baseline optical interferometry. [See Figure 3 for a screen capture and Figure 4 for an orbit plot.]

Future

In addition to the usual growth, the next major release of the Orbit Catalog will try to resolve some of the pairs with multiple orbits, re-examine the list of Calibration Pairs, and the orbit plot will now show the region where systems are predicted to be over the ephemeris period. This will give a visual representation of whether an orbit pair needs to be observed or not. Future editions will probably also include additional elements for systems with combined astrometric/spectroscopic orbits.

3. Fourth Catalog of Interferometric Measurements of Binary Stars (INT4)


History

The 4th Catalog began as an internal database collecting speckle interferometric measures of double stars made by Hal McAlister and other observers into a cohesive collection. The 1984 Catalog, consisting primarily of photographic data, was replaced by the nearly twice as large Second Catalog in 1988 as CHARA was switching from photographic to ICCD data acquisition. This Catalog was maintained on the web for many years and gained a broader definition of interferometry when lunar occultation measures were added in the 1990s. The Catalog moved from Georgia State University to the US Naval Observatory in 1999.
and soon included data from the WDS under a broader characterization of “high resolution.” This includes interferometry, lunar occultation, adaptive optics, satellite observations, and others. Since its origin, the Catalog has contained measures of double stars as well as stars examined for duplicity but were unresolved. It contains over 165,000 observations of more than 47,000 pairs and almost 20,000 never resolved stars. Unlike the WDS this is a comprehensive listing of the measures, not a summary catalog.

Website

The 4th Catalog Website contains various statistical parameters regarding the data, references, and links to all the individual data files, in 1-hour right ascension bands.

Catalog

Each system has an identification line which lists the WDS coordinate and Discovery Designation as well as other cross-identifications, such as HD or HIP number to help identify the system. The data lines are similar to the WDS, but contain additional fields for errors when those are provided as well as information about the filter used for collecting the data.

Future

There is a plethora of new interferometric data from long baseline optical interferometers which have measures of the baseline and visibility, but not the classical position angle and separation. Finding a way to incorporate these data will be quite a challenge.

4. Second Photometric Magnitude Difference Catalog (DM2)

http://ad.usno.navy.mil/wds/dm2.html

History

The Delta-M Catalog owes much of its genesis to the work of G.P. Kuiper. In the early to mid-part of the 20th Century Kuiper discovered many close companions to bright doubles and began a long process of analyzing the multiplicity characteristics of different spectral and luminosity classes. One of Kuiper’s conclusions was that the expected separation-delta-m space for wider, larger delta-m systems was underrepresented. In the middle of the century significant work was initiated to measure the magnitude differences, but not the separation with a variety of specialized instruments (e.g., comparison image micrometers, wedge photometers, double-image and polarizing photometers, area scanners and other methods. Charles Worley, in his perusal of archival publications in the USNO library, collected these in the unpublished, but privately circulated, Delta-M catalog. When the USNO Double Star CD was pressed in 2001 this catalog was included. Since 2001 additional measures of Delta-m have been added as well as the extraction of estimates.
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11182+3132 10 digit approximate position (J2000), as the WDS.
STF1523AB Discovery and component designation, as the WDS.
0.40 Mean magnitude difference.
1 Number of measures contained in the mean.
TtB2000 Reference (keyed to the reference file) from which the measure was extracted.
U Method (keyed to the method file) of the technique used for the measure. The previously unique Delta-m method file and WDS method file, are now the same.

Free form data
Following the listing of methods is a wide free form column which can contain a variety of information, for example, the central wavelength and FWHM of the filter used for the measure, the error of the measure, whether or not it was extracted from the WDS, notes that the measure is uncertain, one (or both) of the components is variable or not in the WDS, when the data was taken, etc.

Future
While the 2MASS Catalog has been matched with the WDS, we've yet to extract the JHK delta-m values from 2MASS.

5. Double Star Library
http://ad.usno.navy.mil/wds/dsl.html

This is the official web page of Commission 26 (Double and Multiple Stars) of the International Astronomical Union (IAU). Three times since the inception of Commission 26 (C26) USNO astronomers have served as president of the Double Star Commission [Kai Strand (1964-1967), Charles Worley (1994-1997), William Hartkopf (2003-2006)]. The Double Star Library has been maintained by the current president for over a decade. It includes membership lists of C26, copies of the more recent (since 1993) Circulars of the Commission, and other C26 and IAU related links. Also included are links to national and international meetings related to binary star research, bibliographies of double star papers over the past several years in professional journals, and links to USNO and other double star catalogs and organizations.
6. Double Star Astronomy at the U.S. Naval Observatory

This was started simply as a site for the Obituary of Charles Worley in 1998. Gradually it collected other information, statistics, photographs and anecdotes about USNO double star astronomers over the years. Generally the website divides the USNO work by method arranging them by micrometry, photography, speckle interferometry, and WFC catalog extraction. Each of these fields has a narrative describing it, a list of USNO astronomers who collected data this way and their contributions to the WDS, photographs from the USNO archive of them as well as related notes. While discovery of new pairs has never been a priority, some of these, as well as the circumstances of their discovery, are enumerated as well. The site also contains USNO contributions to several historically important systems, and obituaries, minor planet announcements, and other supplementary documents related to various USNO astronomers.

7. Washington Multiplicity Catalog (WMC)

Historically, double star data were taken visually, spectroscopically, or photometrically, and while some overlapped, the fields were generally separate. Over the past decades the synergy between techniques has increased and a Multi-Commission meeting was held at the IAU General Assembly in Manchester in 2000 "whose AIM [was] to develop a simple, unambiguous, flexible, and computer friendly designation scheme for stellar companions (including planets)." Several schemes were put forward and it was decided at that time to try the WMC scheme. A half hour band of the sky was prepared and presented at various commission meetings and at a Special Session during the IAU General Assembly Meeting in Sydney (2003). At that time a Working Group was established to produce an all-sky WMC. It is planned to present this at the IAU General Assembly in Prague (2006). The website archives discussions related to these topics and has an online sample WMC for the 1/2 hour band. To see the sample WMC go to http://ad.usno.navy.mil/wds/wmc/wmc110_intro.html.

8. Linear Elements Catalog
(coming soon, no link yet)

There is no link to the Linear Elements Catalog, but this will be included in the next Double Star CD. The WDS, in the column for "O" (i.e., Orbit) has, for ~1500 systems, an "L" indicating a linear solution has been calculated. These pairs with different proper motions are optical pairs that only appear near each other in the sky. The least-squares solution of the linear fit will include the time, position angle, and separation at closest (apparent) approach as well as a differential proper motion in RA and Dec. Figures will be provided which illustrate the quality of the fit. The ephemeris of these systems can possibly provide calibration of a quality greater than that for the Calibration Quality Orbits, described above. In some cases, orbital motion can be seen in the linear fit due to motion of one which is not strictly linear. Some systems, as mentioned above, carry a "C" code in the appropriate motion column indicating it has both an orbit and