Visual Measurements of Double Stars

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Abstract: The observations, measurements and proper motion analysis for a selected set of ten binary stars are reported. These tasks comprised the activities in a special mathematics course devoted to research techniques being taught at the Estrella Mountain Community College in Avondale, Arizona. Observations and measurements were taken with a Meade 11" Schmidt Cassegrain Telescope (SCT) using the Celestron MicroGuide™. Companion measurements for several of the binary system were obtained utilizing the Centre de Données astronomiques de Strasbourg (CDS) website which provides access to a complete library of published astronomical catalogs and data tables, available online and organized in a self-documented database.

Introduction and Instrumentation

This observation program is part of a special mathematics class conducted at the Estrella Mountain Community College located in Avondale Arizona. This course is designed to give students an introduction and experience in performing real-world research with end results consisting of data which is of value to the scientific community. Data collected during these observing exercises resulted in data submissions to established database repositories and publications of results. The selection of researching binary stars was chosen since the observation and measurements of double star systems are an area which can be achieved with the use of small telescopes.

The instrumentation used for observations and measurements consisted of a Meade 11" LX200GPS F/10 Schmidt-Cassegrain telescope. The GPS feature made initial setup and calibration fast and easy. Double star measurements were obtained using the Celestron MicroGuide™ eyepiece which is a 12.5 mm F/L Orthoscopic with a reticule and variable LED.

All observations were taken on the campus of Estrella Mountain Community College campus located at 33º 28' 49.46" N, 112º 20' 36.47" W during evening hours which generally consisted of between 6:00 and 9:00 PM local time (01:00 to 04:00 UT). Observations and measurements covered the dates from mid September 2010 through early December 2010.

Selection of Stars

The selection of stars for observation and measurement were taken from the Washington Double Star Catalog (WDS), a web-based repository for double and multiple star information. The WDS is maintained by the United States Naval Observatory and is the world's principal database of astrometric double and multiple star information. The WDS Catalog 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 108,581 systems based on 793,430 means.

The current version of the WDS is updated nightly. The selection of target stars resulted from reviewing the list of both common observed and neglected double stars referenced on the WDS main web page.

The initial set of stars was selected from the neglected list on the WDS main web page. A large number of systems in the WDS may be characterized as "neglected", which include unconfirmed binaries as well as systems which have not been measured for many years. Three sets of lists are provided in WDS format. The first set was compiled using the following selection parameters:

- Separation greater than three arcseconds
- Delta-m (V band) of less than three magnitudes
- Both components brighter than 11th magnitude

Reviewing these lists and after discussion, the selection criteria for stars for this exercise was based on the number of recorded observations and their measurability with available equipment. The refined selection criteria consisted of the following:

- Primary and companion being magnitude 10 or brighter
- At least one magnitude difference between the primary and companion
- Separation distance being greater than 5 and less than 500 arcsecs
- Very few measurements taken on the binary system (less than 5 measurements and more than 20 years since last measurement)

In the process of taking actual measurement data it was determined that many of the stars on the original target list of neglected stars were beyond the observational capabilities of the observing site and the equipment. As results of these limitations, the original list was expanded to include a broader range of stars taken from the 18-24 hour section of the WDS catalog website. The criteria for this expanded list included:

- Primary and companion being magnitude 10 or brighter
- At least one magnitude difference between the primary and companion
- Separation distance being greater than 5 and less than 500 arcsecs

The criterion for very few measurements on the target star was relaxed.

Preliminary Analysis Using CDS Tools

Candidate binary systems were subjected to a preliminary analysis on the VizieR catalog access tool and the Aladdin interactive sky atlas, made available by CDS in Strasborg, France. After candidate stars were identified, their location was searched for on the Vizier catalog, and a corresponding photographic plate of that region was brought up in the Aladdin sky atlas. These photographic plates were then analyzed to facilitate identification of the binary star system for observation periods, and to ascertain more up to date separation and magnitude data.

An example of taking a separation measurement for ARY 52 off a photographic plate provided by the Aladdin interactive sky atlas is shown in Figure 1. Examples of obtaining additional identification data with the resulting measurements is shown in Figure 2.

Visual Measurements of Selected Binary Stars

Measurements of the separation distance and position angle of the selected binaries was accomplished using a standard visual observational approach. In order to produce high quality measurements, care was taken in calibrating the measurement instrument and performing a series of test measurements for validation of results before proceeding to the measurements of the target stars.

MicroGuide Calibration

The technique for calibrating the MicroGuide was the standard star drift method. The calibration proc-

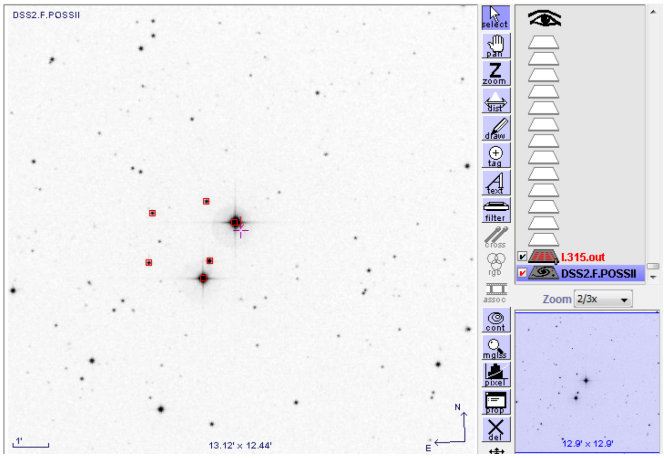


Figure 1: Separation Distance Measurement for ARY 52

ess was carried out over several nights using all observers in order to minimize any observer and instrumentation bias. The star Vega was selected as the calibration star since it was high in the zenith and is clearly visible at magnitude 0.0. Once Vega was oriented in the eyepiece, the telescope's clock drive was switched off and the star allowed to drift the length of the calibration line. After an observer's timing measurement was acquired, the telescope's drive was reactivated and the star repositioned to begin another timing run. A different observer took the next timing measurement. This round-robin approach was applied to achieve a series of independent measurements for each observer. These measurements were then averaged to produce the calibration for this observing system which resulted in 38.26 seconds per drift. A histogram distribution of drift measurement points is shown in Figure 3.

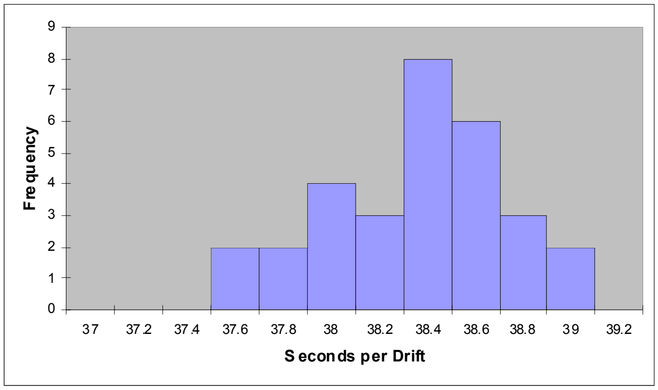


Figure 3: Histogram of Calibration Measurements.

Validation Test

In preparation for beginning actual measurement of selected stars, several well known binary systems were imaged and used as reference to verify the accuracy of our calibration. As an example ε Lyr at 18h 44.3m +39º 40' was used for calibration verification.

Measurements Process

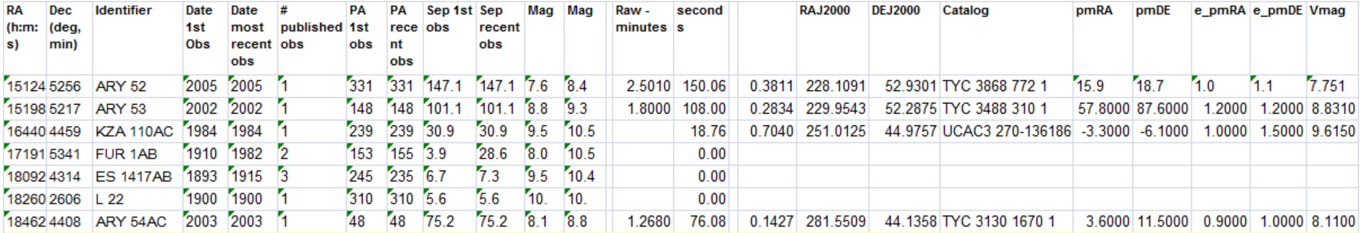
The round robin technique used for taking new measurement data mimics closely those steps taken for the calibration process. Separation was measured by orienting the selected systems along the Microguide's linear scale, and noting their separation as indicated by the scale's tick marks. Position angle was then measured by aligning the binary systems along the linear scale, with the primary star directly on mark 30, and the secondary along the scale between marks 30 and 60. After the stars were aligned, the telescope's tracking system was temporarily disabled, allowing the binary system to drift out of the eyepiece's field of view. The binary system crossed over the circular scale which runs along the edge of the telescope's FOV, as this happened the position of the secondary star along this circular scale was noted. 90 degrees were then added or subtracted from this measurement, depending upon orientation, to achieve our final position angle measurements. These processes were repeated several times per system for separation accuracy. Summary of measurement data are shown in Table 1.

Analysis using Parallaxes and Proper Motions

(The explanation that follows will appear in greater detail in an upcoming Double Star Circular from the The Webb Society, Double Star Section Circular)

Parallax data from the Hipparcos and Tycho catalogs can be used to help narrow down whether or not a star pair is gravitationally bound. While the accuracy of parallax data drops off as a function of star distance it is still a valuable tool when the data is good.

The central problem with parallax data is that often times it is not highly reliable as parallaxes of negative values are sometimes recorded in the HIP and TYC catalogs. There are many cases where a good positive value is given but also examples of where the error in the measurement exceeds the measurement. (For example, the recorded parallax data of HIP 87000 is 27.84 mas, with an error of ±40.94 mas)



RA (h:m:s)	Dec (deg, min)	Identifier	Date 1st Obs	Date most recent obs	# published obs	PA 1st obs	PA recent obs	Sep 1st obs	Sep recent obs	Mag	Mag		Raw - minutes	seconds			RAJ2000	DEJ2000	Catalog	pmRA	pmDE	e_pmRA	e_pmDE	Vmag
15124	5256	ARY 52	2005	2005	1	331	331	147.1	147.1	7.6	8.4		2.5010	150.06		0.3811	228.1091	52.9301	TYC 3868 772 1	15.9	18.7	1.0	1.1	7.751
15198	5217	ARY 53	2002	2002	1	148	148	101.1	101.1	8.8	9.3		1.8000	108.00		0.2834	229.9543	52.2875	TYC 3488 310 1	57.8000	87.6000	1.2000	1.2000	8.8310
16440	4459	KZA 110AC	1984	1984	1	239	239	30.9	30.9	9.5	10.5			18.76		0.7040	251.0125	44.9757	UCAC3 270-136186	-3.3000	-6.1000	1.0000	1.5000	9.6150
17191	5341	FUR 1AB	1910	1982	2	153	155	3.9	28.6	8.0	10.5			0.00										
18092	4314	ES 1417AB	1893	1915	3	245	235	6.7	7.3	9.5	10.4			0.00										
18260	2606	L 22	1900	1900	1	310	310	5.6	5.6	10.	10.			0.00										
18462	4408	ARY 54AC	2003	2003	1	48	48	75.2	75.2	8.1	8.8		1.2680	76.08		0.1427	281.5509	44.1358	TYC 3130 1670 1	3.6000	11.5000	0.9000	1.0000	8.1100

Figure 2: Example of Historical Measurements from VizieR Catalog

Visual Measurements of Double Stars

Table 1: Summary Data for Measures 2010

WDS ID	Discover	Magnitudes		Last			Current		
		Primary	Sec	Epoch	PA	SEP	Epoch	PA	SEP
15124+5256	ARY 52	7.6	8.4	2005	331	147.1	2010.838	330	151.3
15198+5217	ARY 53	8.8	9.3	2002	148	101.1	2010.838	142	108.2
18462+4408	ARY 54AC	8.1	8.8	2003	48	75.2	2010.844	49	76.1
19549+3501	BOT 3AC	6.1	8.5	1958	77	44.6	2010.844	24	40.7
18002+8000	STF2308AC	5.7	8.3	1957	232	18.6	2010.884	231	18.7
23435+5805	ENG 88Aa-E	7.1	9.6	1918	126	159.6	2010.915	196	226.9
18472+1655	ARN 75	6.8	8.6	2004	27	60.2	2010.915	26	65.3
19250+1157	STT 588AB	5.2	8.6	2009	288	101.7	2010.915	281	105.4
20591+0418	STF2737AB-C	5.3	7.1	2009	68	10.4	2010.921	74	12.3
18076+2606	STF2280AB	5.8	5.5	2008	183	14.2	2010.921	184	14.1

For cases where the data is consistent (errors smaller than the measurement), a simple calculation is performed to compute the probable distance to each star. A computation is performed utilizing the following criteria:

1. the distance is assuming the parallax is the measured value less the error
2. the distance is using the measured value
3. the distance is assuming the parallax is the measured value plus the error

A comparison is then performed on the sets of distance calculations of the two components to determine if there is an overlap in the distance bars. If an overlap exists, there is a probability (which varies with the amount of overlap) that the pair is at the same distance and hence a probable binary. If no overlap exists at all, or only a very small one, it is assumed that the pair is optical in nature.

When the parallax of both stars is known, it is a fairly simple process to decide if they are truly binary (bound by gravity due to proximity) or not. The basic premise is that the distance to a star in parsecs is simply the reciprocal of the parallax in arc seconds. Thus a parallax of 10 mas would imply a distance of 1 / 10 x (0.001) = 1 /0.01 = 100 parsecs. If the parallaxes for both the primary and companion are known, the mean distance to both (as well as the upper and lower limits based on the error of the measurement) can be computed and a determination performed to determine whether the pair is close enough to be gravitationally bound. There are actually six classes of distance relationship that must be examined. This is due to the fact that the error values for parallax do have a significant impact on the analysis.

The error values in the parallax must be added to and subtracted from the stated value to give the near and far limits of the star's distance. Three points in space are then defined as PM (the median distance to the primary), PL (the lower distance) and PH (the higher distance). The same process is performed for the companion providing the median and lower/higher points labeling them CM, CL and CH.

Lines are then drawn to scale for each star's distance values and a comparison is performed. The first two cases are related—the stars have no overlap of their lines and hence are not anywhere near close enough to be gravitationally bound. Case 1 is where the distance line for P is closer than C (all of the P values — PL, PM, and PH — are less than their corresponding C values). Case 2 is similar except C is closer than P.

Case 3 is where there is overlap of the two distance lines, with the C lines lying at the low end of the R line, as shown in Figure 4.

Here, CH > PL but CL < PL.

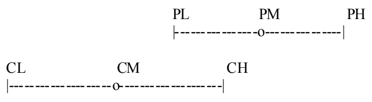


Figure 4: Overlap of Distance Lines

Case 4 is similar but with the C line lying on the right side of the P line, where CL < PH and CL > PL.

Case 5 is where the distance line of C is totally contained in the P line as illustrated in Figure 5.

Here CL > PL and CH < PH.

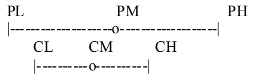


Figure 5: Companion Contained within Primary Uncertainty Line

Case 6 is where the P line is totally contained in the C line.

Taking a pair of Case 1 or Case 2; either case results in the same conclusion—there is 0% probability that the system is bound (physical).

Case 3 (and its sister Case 4) would have an overlap of CH – PL (or CL – PH) along a spread of PH – CL (or CH – PL).

Case 5 (and 6) would have an overlap equal to CH – CL (or PH – PL) out of the range of PH – PL (or CH – CL).

At first glance, it would seem that the odds of the two stars being close enough in space to be physical would be found by simply determining the percentage of the overlap range divided by the total space range. For instance, consider a Case 3 scenario with these values:

PL = 141 pc PM = 177 pc PH = 237 pc
CL = 15 pc CM = 29 pc CH = 225 pc

The overlap is found by taking CH – PL or 84 pc. The total space range is PH – CL or 222 pc. We might then think that the probability of the two stars being close enough to be physically bound would be 84 / 222 or 38%.

But that could be inaccurate due a star's probability of being a distance R is not linear within the error range, but rather a Poisson distribution. There is a very small probability that the true position of the star could be more than three standard deviations from R—but the odds are less than 1%. For all practical purposes, we can say then that there is a roughly 68% chance the star is within one standard deviation of R, a 95% chance it is within two standard deviations of R, and 99.6% it will lie within three standard deviations of R.

This means that we cannot compute the probability of spatial proximity by taking the ratio of the overlap and error ranges, but we must compute the product of the probabilities based on the Poisson distribution.

As a result, a case like our example above would not result in a proximity probability of 38% but something much lower. The overlap in the distance bars is 84 pc. On the primary's bar, 84 pc is 87.5% of the total bar. In the companion's case, 84 pc is 40% of its range bar. We find then a probability of 99.78% that the primary is within binding distance of the companion, but the companion only has a 21.49% of being in that window and the combined probability is then 21.44%. This is 17% lower than a linear assumption. To be fair, the Poisson distribution will not necessarily be symmetrical about the mean distance to each star, but given that the stars must probably be within 0.3 pc of each other to bind at all, this assumption is minimal in impact.

In addition, an analysis is performed taking the proper motions (when known) and comparing the pair's relative displacement over time to the historical measurements. The net motion of each star is calculated over the time indicated by the first and last measurements on record and "normalized" for results. What this means is that whereas both stars will move over time, the interest is in the relative movement between the pair. Hence, only the net change in RA and DEC of the companion relative to the primary is calculated. The net system movement is reviewed to determine whether the resulting predicted rho and theta match the last measurement.

Taking the first measurement and applying the measured proper motion to each star over the length of the pair's history, a relative motion between the two stars is obtained. Once this relative motion is known, it is a simple task to transform this relative motion to the primary's frame of reference and compare the separation (rho) and position angle (theta) to the last measurement. If the result is within a few percentage points of the actual measurement, the pair is optical, all the motion in the system being accounted for by proper motion. This is because proper motion is linear, whereas the movement of stars in a true binary will, over time, trace out part or all of an ellipse (depending on the inclination of the orbit to earth; the greater the inclination, the more linear the motion becomes as the companion passes near the primary and achieves greatest curved motion at the extremes of the orbit as viewed from earth).

Results of Proper Motion Analysis

Once measurement data was obtained, a proper motion analysis based on the above procedure was performed to determine the probability of the stars belonging to a true binary system. Summary analyses of the observed stars are shown in Table 2.

To elaborate on Table 2 using the above described process, a detailed analysis for the first five binaries is provided below.

ARY 52 has a 99% chance of being an optical pair as the proper motion fits the actual measurement history almost exactly. Parallax data is not useful as we only have parallax on the primary. If the pair is physical, the two stars can be no closer than 19,500 AU at this epoch.

ARY 53 has a 97% chance of being an optical pair. Parallax data is not usable, but if they were physical, they could be no closer than 5,900 AU at this epoch.

ARY 54 AC has a 99% chance they are optical. Parallax is not usable, but if physical, they can be no closer than 22,500 AU.

BOT 3 AC: no companion close to the Bottger 2008 position could be located on the POSS II plates. The star which was located at the position in the WDS would be 370 parsecs away, but with no companion nearby, this is not of much use.

STF 2308 AC has a 99% chance they are optical. Both stars have parallaxes, so a parallax study shows the primary to be 64 parsecs away (+18 / - 12) and the companion to be 73 parsecs away (+59 / - 23). There is thus an overlap of the Gaussian probability curves along 99% or so of the primary's distance window. The combined probability of a distance match would be about 85%. However, if they are physical they must be at least 14,200 AU apart at this time.

Conclusion

These observations provide additional information for researchers to investigate the nature of binary systems.

Table 2: Probability of Optical Pair

WDS ID	Discover	Probability of Optical Pair
15124+5256	ARY 52	99
15198+5217	ARY 53	97
18462+4408	ARY 54AC	99
19549+3501	BOT 3AC	Unknown
18002+8000	STF2308AC	99
23435+5805	ENG 88Aa-E	80
18472+1655	ARN 75	96
19250+1157	STT 588AB	98
20591+0418	STF2737AB-C	53
18076+2606	STF2280AB	90

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