Submitted to the *Journal of Double Star Observations*, May 2015

CCD Astrometric Measurements of WDS 04155+0611

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Abstract: Twenty-two separations and position angle astrometric measurements were made of the multiple star system WDS 04155+0611 AB, BC, CD, and CE components. All measurements were compared with historical measurements from the United States Naval Observatory Washington Double Star Catalog which indicate that our astrometric results compare favorably with other recent observations.

Introduction

The Army and Navy Academy (ANA) is a college preparatory Middle and High School with a military structure focused on personal growth and leadership. The ANA Astronomy Club is one of the newest and most active clubs on campus that has grown from an observational club to a group of active astronomical researchers.

In the Fall of 2014, ANA acquired new astronomical equipment through a generous grant from the McMahan Foundation, enabling new research capabilities. Our team, Figure 1, focused on: 1) astrometric analysis of binary stars and 2) calibration of the new telescope system against professional grade equipment.

Figure 1: Junyao Li, Zhixin Cao, Steve Qu, and Jeff Li

The Army and Navy Academy is located on the beach in Carlsbad, CA. Due to this location, there are many nights that the sky is obscured by fog and coastal clouds. As a result, we were not able to make the observations necessary to address our second objective and thus expanded use of the global iTelescope network to perform astrometric analysis using MaximDL and Mirametrics Mira Pro x64. The research and CCD Imaging focused on a single double star, WDS 04155+0611, seen in Figure 2.

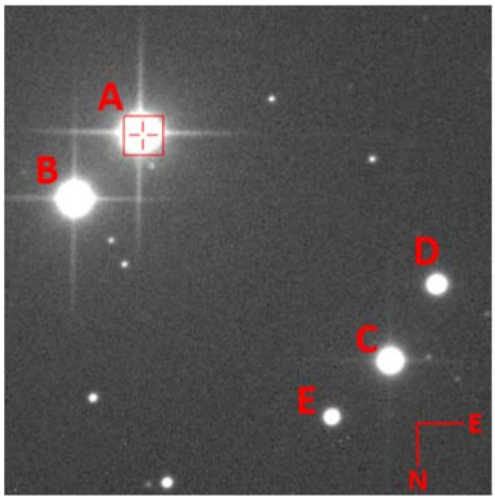

Figure 2: WDS 04155+0611 with the A component marked by a red square in Mira Pro x64.

Equipment and Procedures

Two different telescope/camera combinations were selected from the iTelescope network located at an elevation of 7,500' in New Mexico: T3 and T11. The diversity of these two systems allowed comparative observations to enhance the credibility of the final measurements.

The T3 telescope is a Takahashi TOA-150mm refractor with a 1095mm focal length mounted on a Paramount GTS. The CCD images were acquired with one-shot color SBIG ST-8300C. The resolution of this combination is 1.02 arc seconds per pixel with a field of view of 42.4 x 56.3 arc minutes. As the CCD is a one-shot color, no external filters were used in acquiring these images. The images obtained from T3 were on March 5th, 2015 at an exposure time of 180 seconds.

The T11 telescope is a Planewave 20" CDK with a 2280mm focal length through a 0.66 focal reducer, mounted on a Planewave Ascension 200HR mount. The CCD images were acquired with FLI ProLine PL11002M. The resolution of this combination is 0.81 arc seconds per pixel with a field of view of 36.2 x 54.3 arc minutes. The filters used for these images were a combination of Astrodon red and hydrogen alpha (Ha). The observations with the Astrodon red filter were performed on March 10th and March 27th, 2015, and the hydrogen alpha images were performed on March 27, 2015. The exposure times were 180 seconds for each image.

Once the images were acquired by T3 and T11, they were pre-processed by iTelescope with the appropriate dark and flat images and downloaded to begin the research.

For the CCD image analysis, we utilized MaximDL v6 to perform astrometric calibrations and insert World Coordinate System (WCS) positions into the FITS header. For this process, MaximDL located a number of stars in the CCD image, and then matched them to the Fourth U.S. Naval Observatory CCD Astrograph Catalogue (UCAC4). The astrometric calibration data for each image is outlined in Table 2 below.

WDS	Tel.	Date	Filter	# UCAC4 Stars	RA/DEC	Camera Angle, Focal Length, Plate Scale
04155+0611	T3	3/5/2015	Color	221 of 1216	RA 04h 15m 28.8s, Dec +06° 11' 10.3"	+04° 06.7', FL 1104.8 mm, 1.01"/Pixel
	T11	3/10/2015	Red	420 of 1030	RA 04h 15m 28.8s, Dec +06° 11' 13.2"	+270° 32.2', FL 2265.3 mm, 0.82"/Pixel
	T11	3/27/2015	Red	417 of 1030	RA 04h 15m 28.5s, Dec +06° 11' 06.0"	+270° 13.3', FL 2269.6 mm, 0.82"/Pixel
	T11	3/27/2015	Ha	84 of 120	RA 04h 15m 28.6s, Dec +06° 11' 08.1"	+270° 13.1', FL 2265.7 mm, 0.82"/Pixel
	T11	3/27/2015	Red	415 of 1030	RA 04h 15m 28.7s, Dec +06° 11' 08.5"	+270° 14.3', FL 2269.0 mm, 0.82"/Pixel
	T11	3/27/2015	Ha	37 of 120	RA 04h 15m 28.7s, Dec +06° 11' 09.8"	+270° 13.5', FL 2263.1 mm, 0.82"/Pixel

Table 2: MaximDL astrometric calibration data for each image.

Each image was then opened in Mirametrics Mira x64 Pro to give accurate position angle and separation of our double star systems. To verify the signal per pixel acquired on the FITS image, designated by pixel value (ADU) for each column on the CCD chip, the values were plotted in a 3-D image plot in Figure 3.

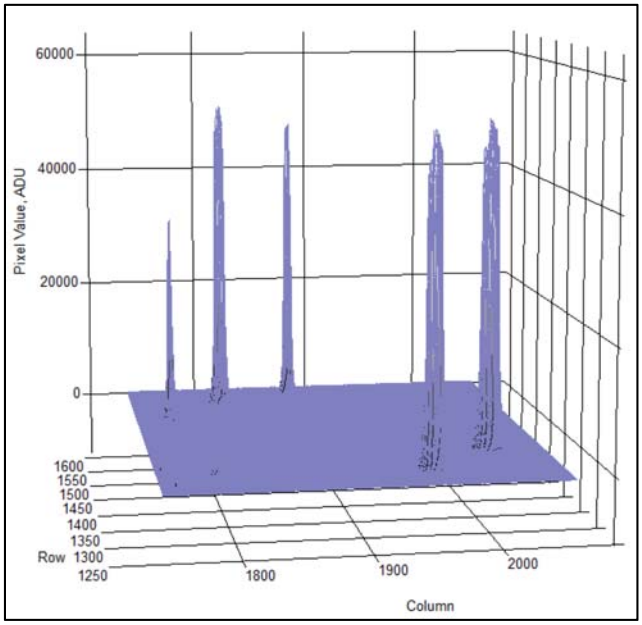

Figure 3: 3D Plot of the Pixel Value ADU vs. Position on the CCD Image with Mira Pro x64.

Satisfied that the image was representative of the FITS file, the signal level and saturation of the A and B stars respectively were examined through a separate graphing of the pixel value seen in Figure 4.

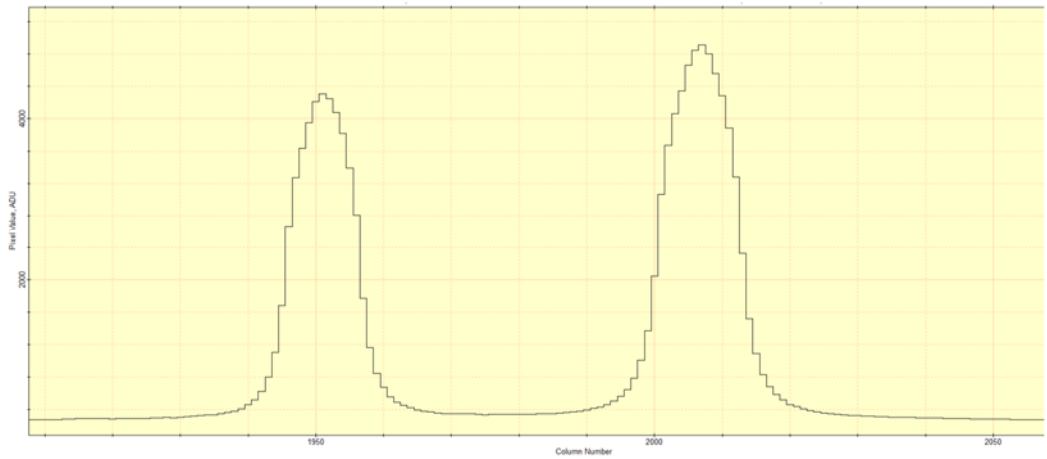

Figure 4: Graphical Plot using Mira Pro x64 when determining the position angle and separation of the AB pair.

Having correctly identified the A, B, C, D, and E stars in this binary star system, each combination was measured for position angle and separation. Mira Pro assists accuracy in measurements by locating the centroid of each star being measured, records the centroid RA and Dec, and then calculates the position angle and separation between the stars. Figure 5 shows Mira Pro measurement of the AC pair of WDS 04155+0611.

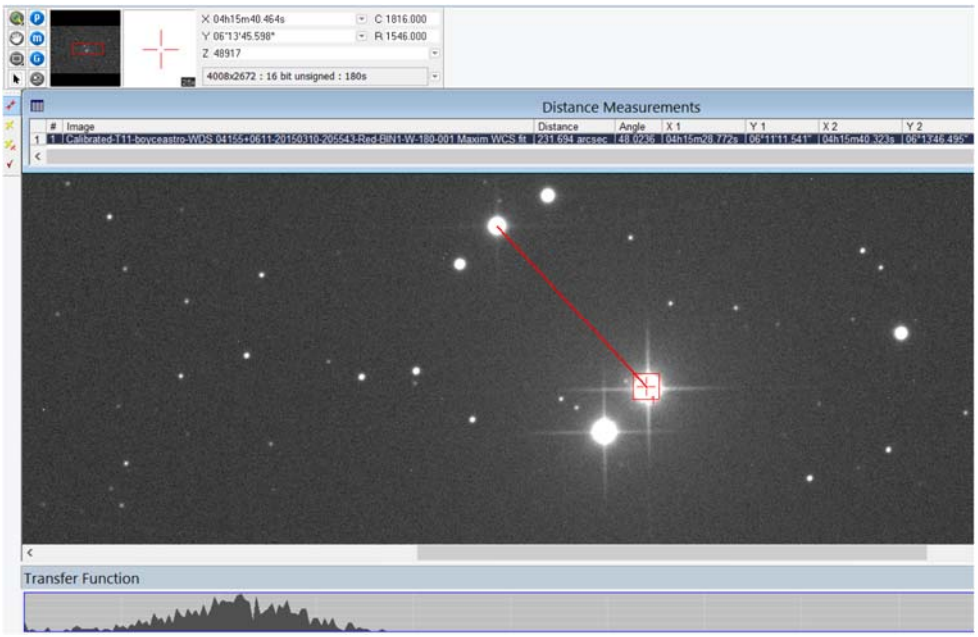

Figure 5: Mira Pro measurement of the AC pair of WDS 04155+0611.

Microsoft Excel was then used to calculate the standard deviation and standard error of mean from the astrometric results.

Results

Table 3 shows the observational results for pairs AB, AC, CD, and CE of WDS 04155+0611 with the following data: Pair Name, Epoch, iTelescope number (aperture), Filter, Position Angle, and Separation. In the heading please note that both telescopes are located in New Mexico and all exposures were 3 minutes in length. In the last 3 rows of each pair measured in Table 3, we provide the average of the measurements, standard deviation, and the standard error of the mean for separation in arc seconds and position angles in degrees.

TEAM HAWK IMAGE DATA **WDS 04155+0611**

Telescopes
iTelescope # (aperture in meters)

Both are in New Mexico; all 3 minute exposures

Filter codes	
red (A)	Astrodon red
Ha	hydrogen alpha

AB Pair

Epoch	Telescope	Filter		Position Angle	Separation
2015.175	T3 (.15)	color		315.069	64.805
2015.189	T11 (.5)	red (A)		314.508	64.761
2015.249	T11 (.5)	Ha		315.733	64.176
2015.249	T11 (.5)	Ha		315.778	64.234
2015.249	T11 (.5)	red (A)		316.662	63.623
2015.249	T11 (.5)	red (A)		315.721	64.220
		Average		**315.58**	**64.30**
		Standard Deviation		**0.73**	**0.44**
		Std. Error of Mean		**0.122**	**0.073**

AC Pair

Epoch	Telescope	Filter		Position Angle	Separation
2015.175	T3 (.15)	color		48.028	232.213
2015.189	T11 (.5)	red (A)		48.029	233.026
2015.249	T11 (.5)	Ha		48.131	232.774
2015.249	T11 (.5)	Ha		48.131	232.797
2015.249	T11 (.5)	red (A)		48.119	234.665
2015.249	T11 (.5)	red (A)		48.115	232.586
		Average		**48.09**	**233.01**
		Standard Deviation		**0.05**	**0.86**
		Std. Error of Mean		**0.008**	**0.143**

CD Pair

Epoch	Telescope	Filter		Position Angle	Separation
2015.175	T3 (.15)	color		314.797	55.449
2015.189	T11 (.5)	red (A)		314.408	55.925
2015.249	T11 (.5)	Ha		314.411	55.913
2015.249	T11 (.5)	Ha		314.460	55.895
2015.249	T11 (.5)	red (A)		314.664	55.876
2015.249	T11 (.5)	red (A)		314.536	55.865
		Average		**314.55**	**55.82**
		Standard Deviation		**0.16**	**0.18**
		Std. Error of Mean		**0.026**	**0.031**

CE Pair

Epoch	Telescope	Filter		Position Angle	Separation
2015.175	T3 (.15)	color		148.869	62.173
2015.189	T11 (.5)	red (A)		149.404	61.821
2015.249	T11 (.5)	Ha		149.404	61.807
2015.249	T11 (.5)	Ha		149.403	61.817
2015.249	T11 (.5)	red (A)		149.342	61.954
2015.249	T11 (.5)	red (A)		149.283	61.870
		Average		**149.28**	**61.91**
		Standard Deviation		**0.21**	**0.14**
		Std. Error of Mean		**0.035**	**0.024**

Table 3: Position Angle and Separation measurements, average, standard Deviation, and Standard Error of Mean for all pairs of WDS 04155+0611.

Discussion

Noted in Table 3, the standard deviation (Frey et al, 2010) of the separation of pairs CD and CE are smaller than pairs AB and AC. The AC separation standard deviation is small however when compared to the total separation (0.86"/233.01" or 0.36%). This pair's wide separation enables a very accurate position angle measurement for AC with a small standard deviation (0.05"). The relative brightness of the A and B stars may have introduced variation in the centroid approximation computed by the software which may account for the greater separation and position angle standard deviations for the AB pair. The measurements of the AC, CD, and CE pairs with the T-3 telescope have greater position angle and separation deviations than those obtained by the T11 telescope. Aside from the lower resolution provided by the 150mm T3 telescope, one other possible explanation for these greater deviations is that the T3 telescope uses a Bayer Matrix over each pixel in order to obtain a one-shot color image rather than a single filter such as red or Ha in the T11 telescope/CCD system. One may also note a greater consistency in the T11 measurements with Ha filter compared to the red Astrodon filter, especially for the AB and AC pairs.

The results of the measurements compared to the published Washington Double Star data are provided in Table 4. For each pair, the first and last measurements are given with our 2015 data to the right. The results are consistent with recent observations.

WDS Number	Pair	Observations			Position angle			Separation		
		WDS Catalog			WDS Catalog		*NEW*	WDS Catalog		*NEW*
		#	First	Laast	First	Last	*2015*	First	Last	*2015*
04155+0611	AB	37	1875	2012	314.8	315.9	*315.069*	65.47	64.0	*64.3*
	AC	13	1885	2011	47.4	47.7	*48.09*	213.3	234.42	*233.01*
	CD	11	1897	2012	317.5	314.6	*314.55*	51.669	55.63	*55.82*
	CE	9	1961	2012	144.8	149.4	*149.28*	57.249	61.39	*61.91*

Table 4: Our 2015 measurements compared to the WDS published measurements.

The data displays a pattern of substantially more rapid relative motion for the C component away from the AB pair than the AB pair's relative motion. These motions are displayed, through their historical measurements, in Figures 6 and 7.

The AB pair in Figure 6 displays limited transverse velocity over the past 140 years of B relative to A. A closer analysis will reveal that the upper and lower data points for B in Figure 6 are only from two disparate measures in the 1980s. All other 35 measurements cluster closely around the middle point for B in Figure 6.

The AC pair however shows substantially greater transverse velocity in C's apparent motion away from A. Figure 7 depicts this apparent linear transverse motion of C away from A over the past 130 years. A dotted least squares linear trend line has been overlaid on the observed data in Figure 7.

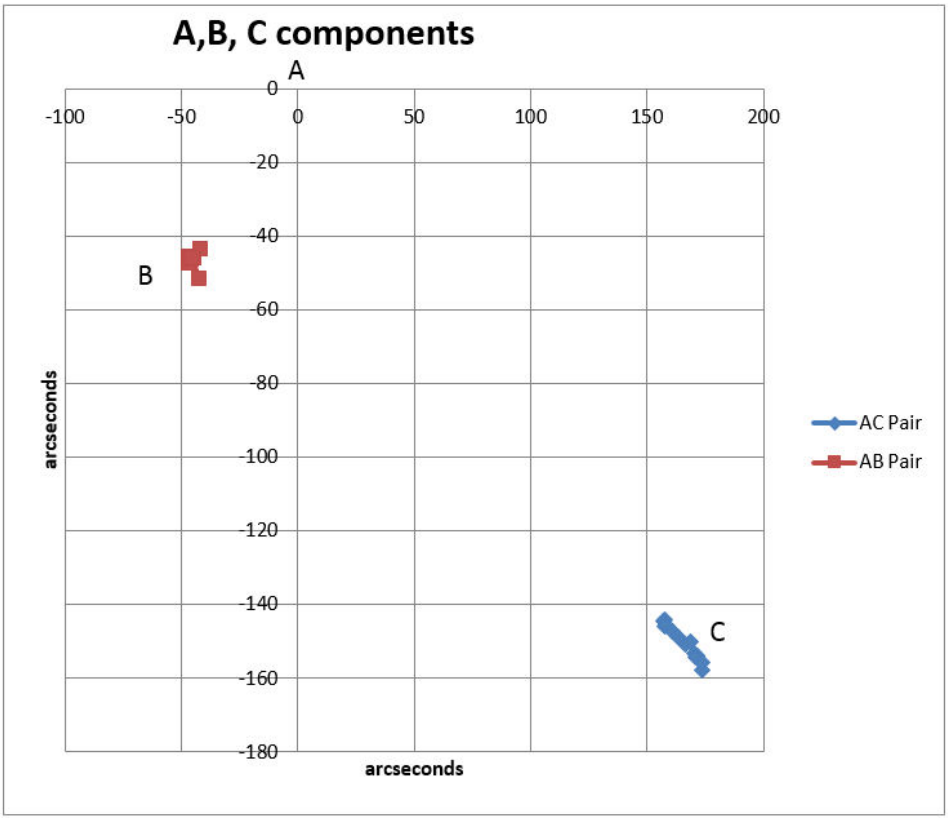

Figure 6: B and C component movement relative to A.

Figure 7 provides an expanded view of the transverse motion of C away from A.

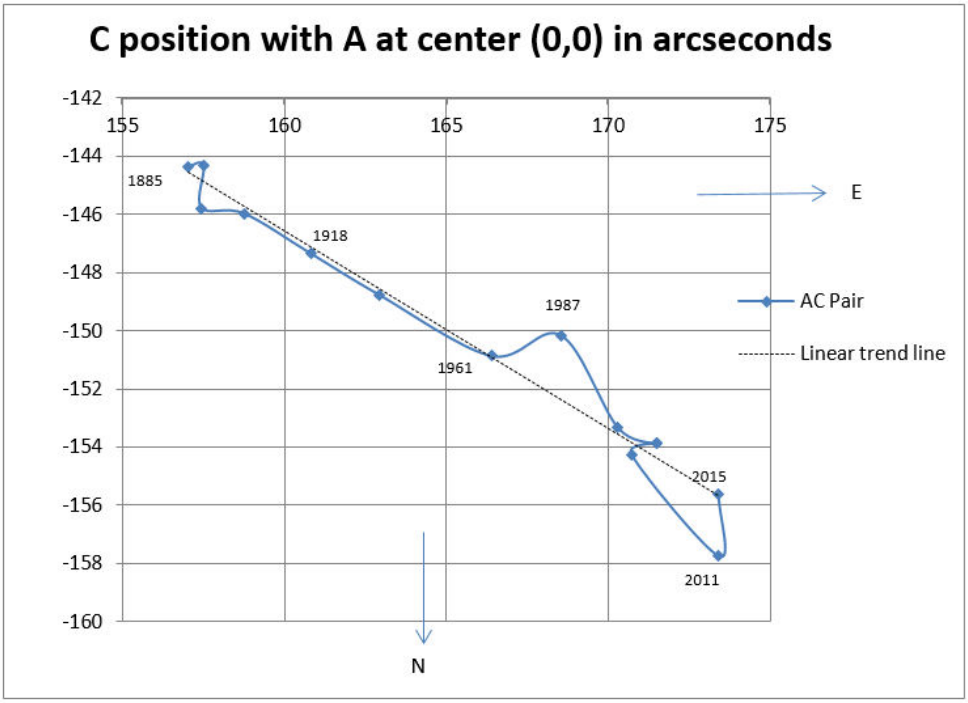

Figure 7: C movement relative to A.

In Figure 8, the D and E components have been measured historically relative to C. They have greater relative motion around the C component than the relative motion of the originally discovered AB pair as recorded in their published measurements. One may note a more consistent apparent motion of the E component compared to C than the D component compared to C.

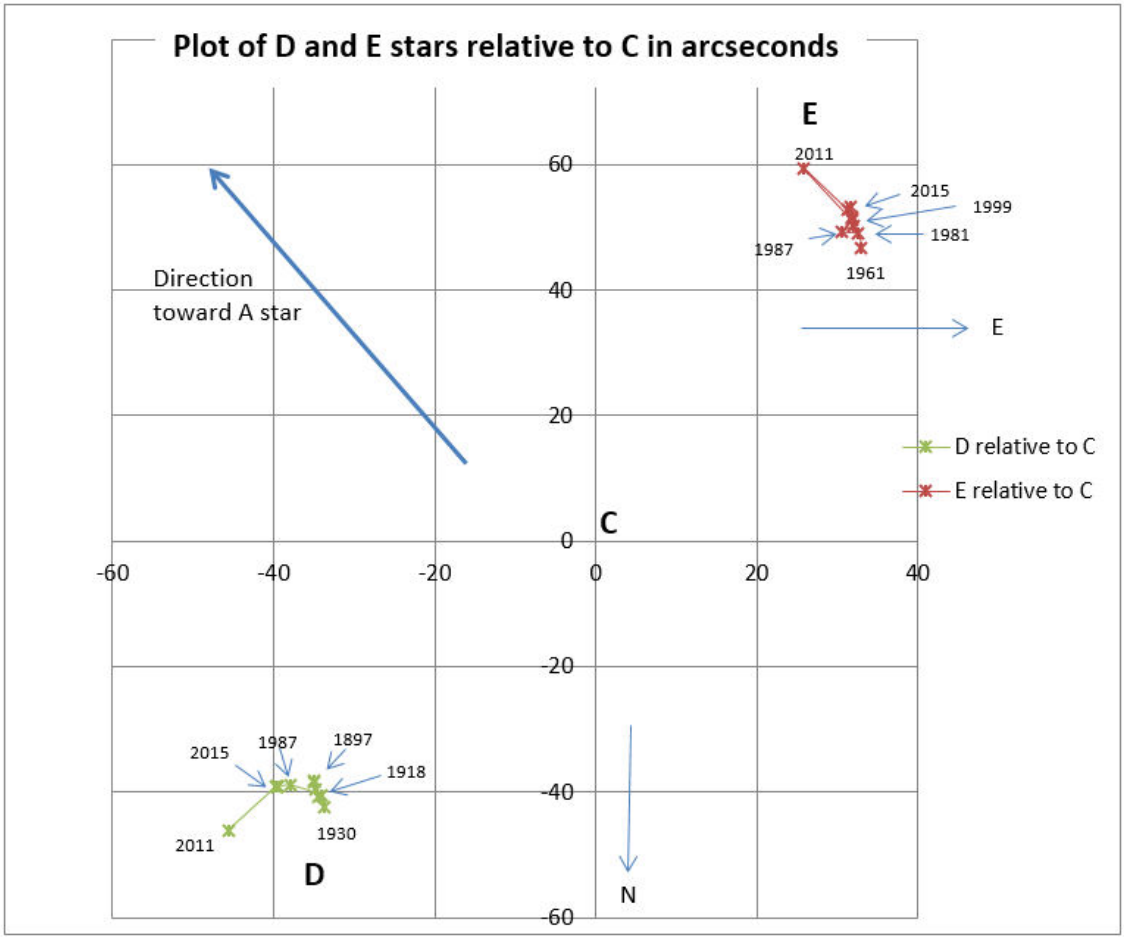

Figure 8: D and E published measurements relative to C.

Acknowledgements

We thank the United States Naval Observatory for providing historical measurement data. We thank the Boyce Research Initiatives and Educational Foundation (B.R.I.E.F.) for providing access to the iTelescope network and certain software and Mirametrics for providing access to Mira Pro x64 for accurate astrometric measurements of our binary star system. We thank Russ Genet for providing guidance.

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