Astrometric and Photometric Measurements of Seven Double Stars in the Crux

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Abstract

We determined the angular separation, position angle, and brightness difference of seven double stars in the Crux as part of an astronomy course held in the first half of 2023 at the Feira de Santana campus of the Universidade Federal do Recôncavo da Bahia (Brazil). We used images of these double stars from Feira de Santana and from the Digital Sky Survey 1, red and infrared, which allow characterization of these double stars at different epochs and spectral ranges. Our astrometric parameters agree with the near-equivalent epoch parameters from the Washington Double Star Catalog, although there were minor discrepancies due to data reduction. In four of the five double stars with a defined brightness difference, component A is redder than component B.

1. Introduction

An optional astronomy course was established at the Feira de Santana Campus (Brazil) of the Universidade Federal do Recôncavo da Bahia (UFRB) in the first half of 2023. The proposed observational project for this course was the astrometric and photometric characterization of double star systems due to their importance in stellar astrophysics. The celestial region where the double stars examined in this study are located is Crux, as the Brazilian nation has a cultural connection to this constellation. Brazil is a country in the southern hemisphere whose sky has an easily identifiable asterism: the Southern Cross, or simply Crux. The Crux is the central asterism in our national flag. It shows a celestial planisphere and represents the sky observed from Rio de Janeiro at 8:30 a.m. local time on November 15, 1889, when the Brazilian Republic was founded (Brasil, 1992). In addition, Crux was high in the sky, with an altitude of over 40 degrees on the evening when our course took place. We selected mainly poorly observed double stars in the Crux region by combining data obtained with a telescope installed at the UFRB campus in Feira de Santana and from the Digital Sky Survey (DSS).

Our goal in this study was to make new measurements of the angular separation ρ, position angle θ, and brightness difference Δmag between the components A and B of each analyzed double star at different epochs and spectral bands. In this study we have defined the angular separation, the position angle and the difference in brightness between the double star components as astrometric and photometric parameters, respectively. We do not intend to investigate whether these double stars are gravitationally bound.

2. Equipment, Data and Methods

In this project, we analyzed seven double stars. All double stars were selected using a combination of two parameters available in the Washington Double Star Catalog (WDS) version of April 22, 2023 UT: a) a minimum angular separation of three arcseconds, which corresponds to typical seeing at an urban observing site such as Feira de Santana (Racine & Wesemael, 2008), and b) double stars with the lowest number of observations.

The identification of the double star analyzed in this study and their astrometric data available in the WDS catalog can be found in Table 1.

Table 1. Information on the double stars analyzed in this study in the WDS catalog. ID is the identification of the double star in the catalog, N is the number of measurements, Beginning and End are the first and last year of the available data in the WDS catalog. θb, θe, ρb, and ρe are the position angle (degrees, º) and angular separation (arcseconds,”) corresponding to the beginning and end years, respectively.

ID	Beginning	End	N	θb	θe	ρb	ρe
12249-5807 BSO 8	1834	2020	27	336	334	4.5	4.7
12546-5711DUN 126AB	1826	2020	39	10	17	35.9	34.5
12107-5849HJ 4503	1834	2016	15	250	247	6	7.9
12223-6117TOB 63AC	1987	2015	4	169	169	24.4	24.7
12198-6030B 9018AC	1938	2015	4	126	125	17.4	17.6
12322-5852TOB 88	1892	2015	6	101	91	15.4	14.7
12390-6408TOB 109	1923	2015	7	33	32	32.9	32,1

The double stars 12249-5807 BSO 8 and 12546-5711_DUN 126AB were observed in Feira de Santana using a Meade ACF 0.20-meter f/10 telescope with a LXD 75 German equatorial mount, equipped with a ZWO ASI174MC CMOS camera without filter. A sequence of hundreds of images of the objects was taken with an exposure time of 5 seconds. These images were aligned and stacked using FireCapture software. The images were selected using the Bayer Drizzle algorithm, which selected the images with the better signal-to-noise ratio (Figure 1 top).

The remaining double stars were analyzed using Digital Sky Survey (DSS) images in its DSS-1, DSS2-red, and DSS2-infrared versions (Figure 1 bottom), a procedure previously used in Lopez et al (2011a, 2011b). The photographic plates used in these surveys have their maximum quantum efficiency at 420, 645, and 805 nm, respectively (Morgan, 1995; CADC, 2023). The CMOS camera used for the unfiltered images obtained by our group has a maximum quantum efficiency between DSS-1 and DSS2-red.

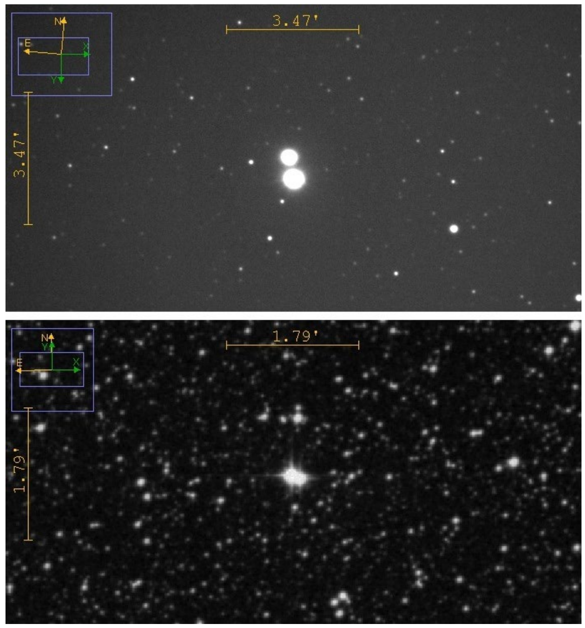

Figure 1: Examples of the double star images analyzed in this study: Mu Crux or 12546-5711DUN 126AB (top), taken at Feira de Santana on June 23, 2023 UT and DSS2-red image of 12107-5849HJ 4503 (bottom), taken on April 20, 1991 UT. The images were created with AstroImageJ software.

All DSS data were taken with the UK Schmidt Telescope (UKST) in Australia between the 1970s and 1990s. The DSS2-red, infrared, and Feira de Santana images have virtually the same plate scale, 1.01 and 0.932 arcsec/pixel, respectively. DSS-1 was imaged with "new optics" as defined in the image headers, giving the telescope an image scale of 1.70 arcsec/pixel.

Regardless of the source, all scientific images were measured using AstroImageJ software (Collins & Kielkopf, 2013). We have chosen the option of this software to determine the centroid of the point spread function (PSF) of each component of the double star system. For this determination, the user of the software has defined a starting position for the centroid search. This search took place in a circular region centered on the user's starting position. The radius of this circular region was initially set to the full width at half maximum (FWHM) of PSF. This value corresponds to about 8 arcseconds for a bright component A of the double stars observed at Feira de Santana or for DSS2-red and infrared images of 12390-6408TOB 109. The size of this circular region had to be adjusted due to the different plate scale in the DSS-1 data and/or to avoid the field stars being in this aperture. It was possible to double stars with a separation greater than the FWHM. The photometric and astrometric parameters of the double stars in this condition (12223-6117TOB 63AC, 12198-6030B 9018AC, 12322-5852TOB 88, and 12390-6408TOB 109) were invariant regardless of the initial position specified by the user due to the use of the centering algorithm. These parameters were measured once, and AstroimageJ does not define errors for these individual measurements. For systems with an angular separation of less than the FWHM as 12107-5849HJ 4503, we found no reliable astrometric and photometric measurements because the centroid of the PSF of the two stars in the system was within this aperture radius. Similar low reliability was found for the two components of 12546-5711DUN 126AB and component A of 12249-5807BSO 8, which are slightly overexposed. For the latter three systems, we deactivated the automatic centering algorithm and measured these astrometric and photometric parameters five times in the same image. The variation of these parameters is related to the random variation of the position of the centers of the point distribution function of each star defined by the user. In this situation, the system parameters are represented by their average values and their dispersion is given by the average deviation in Tables 2, 3, 4 and 5 for the double stars 12249-5807BSO 8, 12546-5711DUN 126AB and 12107-5849HJ 4503.

Since the AstroimageJ software does not provide error information for individual measurements, we report the position angle, angular separation, and difference in brightness for the double stars 12223-6117TOB 63AC, 12198-6030B 9018AC, 12322-5852TOB 88, and 12390-6408TOB 109 to the same decimal places as the corresponding measurements of the double stars 12249-5807BSO 8 and 12546-5711DUN 126AB (Table 2) and 12107-5849HJ 4503 (Table 4), respectively. This number of decimal places was determined by the average deviation of the measurements of these stars.

Table 2. Double stars observed at Feira de Santana.

ID	Epoch (UT)	θ (º)	ρ (”)
12249-5807BSO 8	2023.500	334±2	4.8±0.3
12546-5711DUN 126AB	2023.564	17±1	34.6±0.8

Table 3. DSS2-infrared double stars analyzed in this study.

ID	Epoch (UT)	θ (º)	ρ (”)	Δmag
12107-5849HJ 4503	1979.508	251±1	7.35±0.06	0.117±0.005
12223-6117TOB 63AC	1979.508	169	24.9	1.16
12198-6030B 9018AC	1979.508	124	17.2	1.32
12322-5852TOB 88	1978.524	92	14.7	0.23
12390-6408TOB 109	1980.198	32	32.1	1.30

Table 4. DSS-1 double stars analyzed in this study.

ID	Epoch (UT)	θ (º)	ρ (”)	Δmag
12107-5849HJ 4503	1987.350	242±2	7.0±0.3	0.06±0.02
12223-6117TOB 63AC	1987.350	169	25.0	1.07
12198-6030B 9018AC	1987.350	124	16.6	1.44
12322-5852TOB 88	1987.148	92	14.7	0.20
12390-6408TOB 109	1987.350	32	32.2	1.44

Table 5. DSS2-red double stars analyzed in this study.

ID	Epoch (UT)	θ (º)	ρ (”)	Δmag
12107-5849HJ 4503	1991.389	248±2	7.39±0.04	0.037±0.002
12223-6117TOB 63AC	1991.389	169	25.0	0.72
12198-6030B 9018AC	1991.389	122	16.6	0.72
12322-5852TOB 88	1991.366	91	14.2	0.11
12390-6408TOB 109	1996.386	32	32.1	0.88

4. Discussion and Conclusions

Our estimates of the astrometric parameters are compatible with the range of variation proposed in the WDS catalog and listed in Table 1. We compared the data from Tables 2 and 5 with the latest available measurement of angular separation and position for each double star in Table 1 and calculated their percent errors. The median percent errors of the angular separation and the position angle are 2.1% and zero, respectively. This percent errors can be explained by the precision of these measurements, which have median relative standard deviations of 3.3% and 0.9%, respectively, based on the errors reported in Tables 2, 3, 4, and 5.

The brightness difference Δm not only expresses the difference between the apparent magnitude between components A and B of a double star but can also define the difference between the color/spectral types of the components when measured in different spectral regions. If we assume that the components are not variable stars, we can deduct from the comparison of the brightness differences in Tables 3, 4, and 5 that the components A of the double stars 12223-6117TOB 63AC, 12198-6030B 9018AC, and 12390-6408TOB 109 are redder than their components B. There is no clear difference between the colors of the components of the double star 12107-5849HJ 4503, and 12322-5852TOB 88 is slightly red.

This work not only provides new estimates of the astrometric and photometric parameters of seven double stars in the Crux region at different epochs and spectral ranges, and virtually doubles the number of available measurements for some double stars, but also demonstrates that the study of these objects can be carried out by undergraduate students with minimal instrumental and computer resources. Important topics in modern physics, stellar astrophysics, and probability and statistics used in data analysis can be taught during this activity.

Acknowledgements

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